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Evaluation of the E-SOx Process on the EPA Pilot Electrostatic Precipitator

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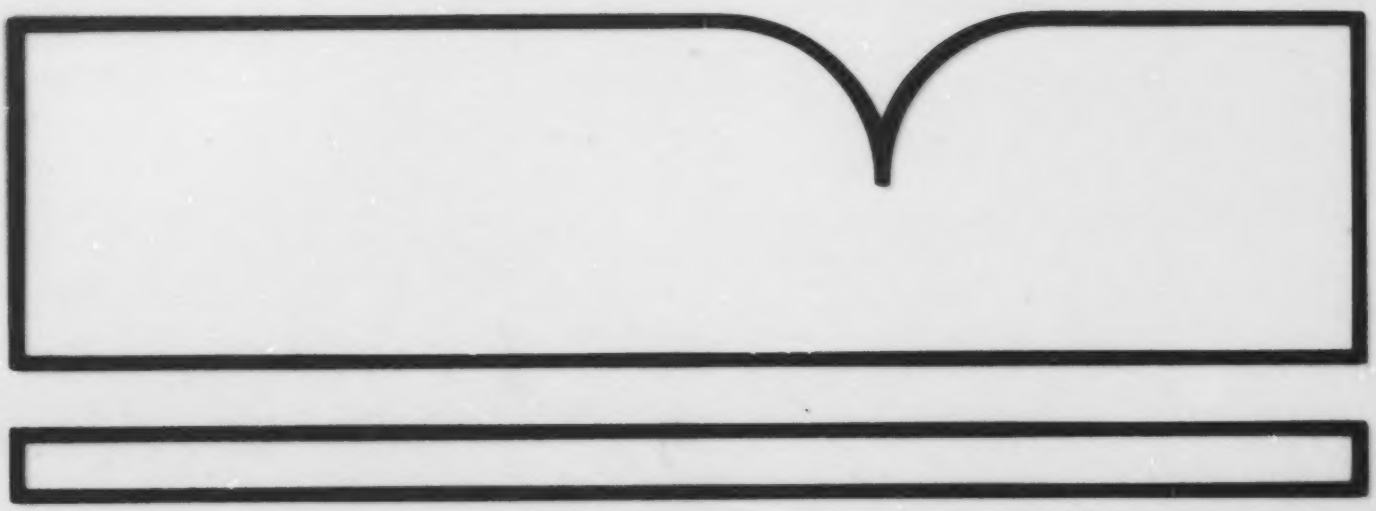

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AN EVALUATION OF THE E-SO_x PROCESS ON THE EPA PILOT ELECTROSTATIC PRECIPITATOR

by

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16. ABSTRACT The report gives results of a small pilot-scale evaluation of the E-SOx process, undertaken to obtain information needed to conduct a planned 5 MWe field pilot demonstration. The process uses an electrostatic precipitator (ESP) for combined sulfur dioxide (SO_2) removal and particulate collection. The concept of spray drying is introduced to the inlet and/or first section of the ESP in which electrical components are removed. Because of the many ESPs at coal-fired power plants, the process is well suited to retrofitting. Evaluation results indicate that a 50-60% SO_2 removal at a calcium/sulfur ratio of 1.2-1.4 can be obtained. Furthermore, this SO_2 reduction can be achieved without degrading the particulate emissions even though the process requires a reduction in the collecting surface of the ESP. The use of a temperature-controlled electrode precharger to compensate for collecting surface loss is also described.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Pollution Combustion	Pollution Control	13B 21B
Electrostatic Precipitators	Stationary Sources	
	E-SOx Process	13I
Sulfur Dioxide	Particulate	07B
Particles		14G
Coal		21D

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ABSTRACT

E-SO_x is a proposed retrofit system that makes use of an existing electrostatic precipitator (ESP) for combined sulfur dioxide (SO_2) removal and particulate collection. The process was developed from research carried out in the Air and Energy Engineering Research Laboratory in the mid 1980's. The work described here is a small pilot-scale evaluation of the process to gather information needed for a planned 5 MWe field pilot demonstration. The results indicate that the process is feasible as a retrofit on power plants where 50 to 60 percent removal of the SO_2 could make a significant contribution toward reducing the amount of SO_2 emitted to the atmosphere. The work describes E-SO_x conditions which can be adjusted to meet the SO_2 removal requirements of the field evaluation that is to follow.

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METRIC EQUIVALENTS

Readers more familiar with metric units may use the following to convert to those units.

Non-metric	Multiply by	Yields Metric
cfm	0.000472	m^3/s
^oF	$5(^oF-32)/9$	^oC
ft_2	0.305	m_2
ft^2	0.0930	m^2
ft^3	0.0283	m^3
gr	0.000648	kg
lb	0.454	kg
psi	6.895	kPa
gpm	0.228	m^3/s

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SECTION 1

BACKGROUND

INTRODUCTION

E-SO_x is a retrofit process for coal-fired boilers, which combines in a single unit electrostatic precipitator (ESP) technology for collecting particles and spray dryer technology for sulfur dioxide (SO_2) removal. The process makes use of a modified existing ESP equipped with an auxiliary system for preparation and injection of a lime slurry into the ESP. E-SO_x is similar to other proposed retrofit lime or limestone-dependent processes in that a dry solid waste is produced that is collected along with the fly ash in the particulate collector, usually an ESP. The concept of E-SO_x appears to offer an attractive option for acid rain mitigation. An economic evaluation of E-SO_x based on reasonable rates of SO_2 removal and lime utilization has indicated that it can be cost effective[1]. Both the economic study and initial report on E-SO_x from this laboratory[2] gave impetus to a large pilot-plant evaluation to be conducted at Ohio Edison's Burger Station sponsored by the U.S. Environmental Protection Agency (EPA) and the Ohio Coal Development Office. Preparation for that pilot plant evaluation started in 1987 and the actual testing is being carried out in 1989. This report covers work that was performed in-house at EPA to verify the original results and to define the parameters that control SO_2 removal. The work reported herein was completed and the technology transferred for use in starting up the field site evaluation.

In the E-SO_x retrofit concept shown schematically in Figure 1-1, the front end of an existing ESP is converted to a spray chamber where contact is made between gaseous SO_2 and lime slurry droplets. Evaporation of the water also takes place in this converted section of the ESP so that the reaction product, excess lime, and fly ash that enter the remaining portion of the ESP are sufficiently dry for efficient ESP operation. The electrical components of the remaining portion are left intact so that the ESP operates as a particle collector. To provide this contacting chamber with a sufficient space to allow a finite drying time of 1 s or greater, the ESP will most likely lose 25 to 30 percent of its collector plate surface. At the same time, the particulate load will increase by a factor of 3 or more. This particulate, a large fraction of which is calcium based, has an extremely high electrical resistivity at normal ESP operating temperatures. The sorbent reaction with SO_2 will eliminate the effects of sulfur trioxide (SO_3) that would tend to lower this resistivity. On the other hand, lowering the gas temperature by the water spray will tend to more than compensate for resistivity increases due to ash composition. From the beginning, the E-SO_x concept has recognized the availability of advanced ESP technology to aid in maintaining good particulate collection performance. Cooled pipe precharging, for example, can be introduced in retrofit ESP's to compensate for less collector surface or changes in resistivity characteristics.

The E-SO_x concept raises two fundamental questions which can be answered only by experiment. The first question concerns the feasibility of removing substantial SO_2 by contacting the rapidly moving gas with slurry droplets and drying the droplets within the space of one ESP section. The second question has to do with maintaining an acceptable level of ESP performance under a reduced collector area and an increased particulate loading.

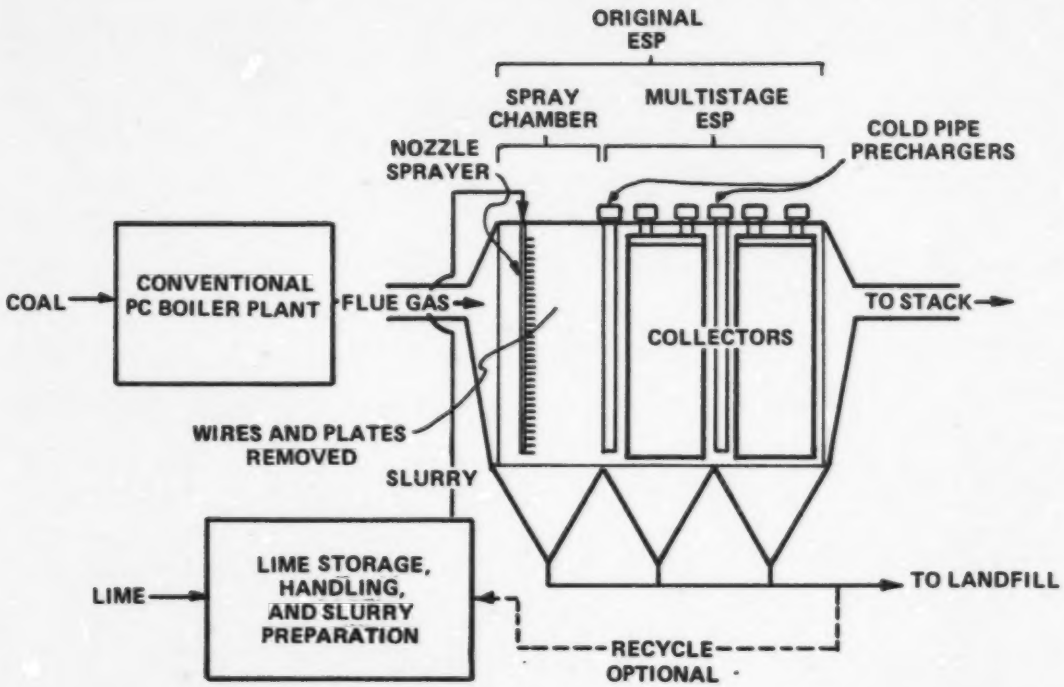


Figure 1-1. Schematic diagram of E-SO_x process.

PROCESS CHEMISTRY

Compared with conventional wet flue gas desulfurization processes, the chemistry of E-SO_x processes is relatively simple.

The overall reaction between SO_2 and $Ca(OH)_2$ may be written as

$$Ca(OH)_2 + SO_2 \text{ <====> } CaSO_3 \cdot 1/2\ H_2O + 1/2\ H_2O$$

This reaction does not occur in a single step but may involve the following equations:

Dissolution

$$SO_2 + H_2O \text{ <====> } H_2SO_3 \qquad (1)$$

Dissociation

$$H_2SO_3 \text{ <====> } HSO_3^- + H^+ \qquad (2)$$

$$HSO_3^- \text{ <====> } SO_3^{=} + H^+ \qquad (3)$$

Dissolution of solids

$$Ca(OH)_2^{(S)} \text{ <====> } Ca(OH)_2^{(aq)} = Ca^{++} + 2OH^- \qquad (4)$$

Crystallization

$$Ca^{++} + SO_3 + 1/2\ H_2O \text{ <====> } CaSO_3 \cdot 1/2\ H_2O\downarrow \qquad (5)$$

Water plays a very important role in the process chemistry since the dissolution of SO_2 and $Ca(OH)_2$ would not occur without the presence of water.

The overall reaction rate is also controlled by the quantity of water injected and by the gas/water/solid contact mechanisms, which are illustrated in Figure 1-2 for the E-SO_x process. The lime slurry, which usually contains 10 to 20 percent solids, is injected into the ESP spray section as fine droplets through an atomizer such as a two-fluid nozzle. When the slurry droplets are in contact with the hot flue gas, SO_2 is dissolved into the water, and reactions (1) through (5) proceed. On the other hand, water is evaporated from the droplets, and the evaporation causes an increase of the flue gas humidity and a decrease of temperature. Very little reaction and SO_2 removal occur after most of the water is evaporated and the droplets are dried. Dry particles are the desirable form of the product not only for meeting the process requirements but also for minimizing wall deposits. The slurry injection operation is very similar to conventional spray drying in that the atomized slurry droplets remove SO_2 as they dry. The main difference, however, is that instead of a separate reaction vessel (the spray dryer), a section of the ESP is used to provide the residence time for drying and SO_2 absorption; consequently, the available times are much shorter (1 to 3 s compared to 8 to 12 s). The E-SO_x process uses the rectangular section of the ESP which is not designed for spray drying and tends to limit the full use of the volume available for SO_2 capture. The E-SO_x spray section also lacks specially designed devices such as the gas disperser of the conventional spray dryer which promotes intimate gas/liquid contact.

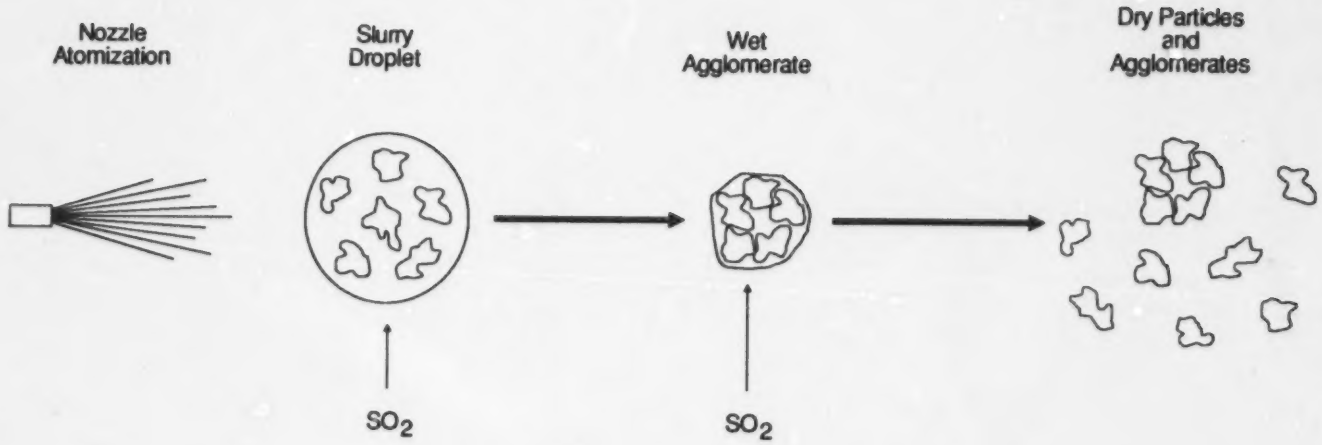


Figure 1-2. Gas/liquid/solid contact mechanism for E-SO_x.

Due to these mass transfer limitations inherent to E-SO_x, the process performance (SO_2 removal and lime utilization) is expected to be less than that of a conventional spray dryer. On the other hand, the E-SO_x concept provides a simple, retrofittable, low-cost process that will be a very attractive alternative when only 50 to 60 percent SO_2 removal is acceptable.

Due to the similarity between E-SO_x and spray drying, the effects of important parameters and the trend observed in conventional spray drying are applicable to the E-SO_x process. In almost all the studies conducted to date, the experimental data have indicated that flue gas relative humidity as reflected by the approach to the adiabatic saturation temperature has a substantial impact on SO_2 removal: the trend is that the closer the approach to saturation, the higher the SO_2 removal efficiency. In conventional spray dryer systems, the effect of approach to saturation or of relative humidity on SO_2 removal efficiency is considered to result from the extended drying time of the slurry droplets that allows a corresponding increased time for the lime/SO_2 reaction to occur in the presence of a liquid water phase. For the E-SO_x process, it is believed that a reduced approach to saturation (higher humidification) similarly increases the water concentration and, thus, extends the reaction time during which sorbent particles can be in contact with liquid water and dissolved SO_2.

Although the previous discussion implies that maximum humidification is desirable, the humidification requirements are also limited by several other factors such as the dryness of the final waste product and the tendency toward wall deposition. Due to the relatively short residence time (usually 2 s or less) of the E-SO_x process, the evaporation and drying of the injected slurry/water droplets cannot be completed if the target humidity or approach to saturation temperature exceeds the heat/mass transfer limit. The wet droplets/particles have a tendency to agglomerate and form cakes on the wall and surface of the duct and ESP. The lowest approach to saturation achieved in a conventional spray dryer has been 15 to 20 ^{o}F. However, in the E-SO_x system, because of the short residence time and less-than-ideal gas/liquid contact, the operable approach to saturation temperature is expected to be higher than the 15 to 20 ^{o}F and most likely in the range of 30 to 50 ^{o}F.

Another parameter that has a significant impact on operating cost and waste product characteristics is sorbent (lime) utilization. In a conventional spray dryer, more than 60 percent utilization has been experienced. However, for E-SO_x systems, lime utilization is expected to be 40 percent or less. In other words, more than 60 percent of the lime used will be unreacted and disposed of as waste. This significant fraction of lime left unreacted would tend to favor an investigation of recycling possibilities, once the E-SO_x process is proven.

Other potentially important parameters include droplet size distribution, residence time, flue gas flowrate, inlet temperature, and SO_2 concentration.

COOLED PIPE PRECHARGER

The use of temperature-controlled anodes to enhance ESP performance is a concept that was first investigated by Penney[3] and White[4]. With this

technique, back ionization is controlled by taking advantage of the relationship between resistivity and temperature. The resistivity of fly ash peaks at about 150 ^{o}C (300 ^{o}F) and decreases at higher and lower temperatures. Therefore, the resistivity can be reduced and back ionization can be controlled by heating or cooling the fly ash on the collector electrodes.

It should be noted that the purpose of cooling the anode is not to cool the gas stream and reduce the resistivity of the particles entrained in the gas but to cool only the dust collected on the surface of the anode. It is only the dust on the anodes that causes the detrimental effects in an ESP. Therefore, by cooling the anodes, the resistivity of the collected dust is reduced, corona current is allowed to flow freely through the dust layer, and the effects of back ionization are eliminated.

The temperature-controlled electrode precharger (TCEP) is attractive because of its simplicity and the ease with which it may be retrofit into an existing ESP. The major component of the device is a manifold of 6.1-cm (2-in.) pipes with inner-spaced corona electrodes. The precharger is installed upstream of one or more electrical sections of the ESP with the pipe manifold normal to the gas flow. As little as 30.5 cm (1 ft) of space between electrical sections is required for installation. Coolant may be passed through the pipes to cool the surface of the collecting electrodes to a temperature sufficiently low to prevent back corona. All the coolant is contained in the pipes; therefore, there is no mixing of the coolant and fly ash. Because the temperature of the pipe is always above the dew point, the fly ash remains dry. The precharger produces a high electrostatic field and high current density which charges the particles to a level that is higher than is possible in a conventional ESP. The result of the higher charge level is an increased migration velocity in the ESP and a net effect of increasing the effective specific collection area (SCA).

The effects of the TCEP can be illustrated by the modified Duetsch equation that is used to size conventional ESP's for power plant applications:

$$Eff = 1 - e^{-(w\,A/V)1/2} \qquad (6)$$

where: Eff = Efficiency
w = Migration velocity, m/s
A = Collector area, m^2
V = Volume of gas treated, m^3/s

It is convenient to discuss the penetration, or amount of ash that exits the ESP, rather than the efficiency of the amount collected. Therefore, it is customary to define penetration as:

$$P = 1 - Eff = e^{-(w\,A/V)1/2} \qquad (7)$$

The 1/2 power in the exponent is used to account for different particle sizes and other non-ideal effects. The migration velocity is proportional to the charge on a particle and the electric field strength:

$$w \propto qE \qquad (8)$$

where: w = Migration velocity, m/s
q = Charge, C
E = Electric field, V/m

The predominant means of charging particles is due to a process that is also proportional to the electrical field strength:

$$q \propto E \qquad (9)$$

In a conventional ESP, the field that produces charging is the same field that forces the charges to the plate. When a TCEP is retrofit into an ESP, two things are different from a conventional ESP: first, the TCEP acts like an ESP and collects a portion of the ash, and second, the TCEP charges the particles, which are then collected in a wire-plate part of the ESP. Because the field in the TCEP is higher than that in the wire-plate section, there is an increase in migration velocity as given by Equation (8). The net result is enhanced collection over that possible in the conventional wire-plate ESP. Table 1-1 summarizes the net effect of this enhanced collection[5]. In this table, "Wire-plate ESP following TCEP" refers to the collector section of the two-stage ESP in which collection is enhanced because the incoming particles are already charged.

The higher field in the TCEP is due to the higher operating voltage and closer spacing of electrodes. The higher fields result in higher migration velocities both in the TCEP and in the rest of the ESP. With the TCEP, the collection efficiency of the wire-plate section is increased from 90.7 to 96.1 percent. The TCEP itself accounts for 71 percent collection. The combined efficiency after retrofit is 1 minus the product of the corresponding penetrations. The result is 98.9 percent. The last line gives the SCA of a conventional ESP that would be required to obtain the same collection efficiency as the retrofit ESP. Thus, it can be seen that approximately 30 percent as much collector plate area is required in the retrofit ESP than for the conventional wire-plate ESP without the TCEP.

Water-cooled electrodes have been successfully demonstrated in Japan[6] where the entire collector plate is cooled. The collected dust is then removed from the collection surfaces by means of mechanical scrapers. A water-cooled cold pipe precharger also has been tested in a two-stage ESP[7]. In these tests, the precharger was installed upstream of parallel plate-plate collectors. The results of these tests showed that the TCEP functioned well. Even with the flat plate-plate collectors, the two-stage ESP was able to obtain 99.4 percent collection efficiency with an SCA of 45.5 s/m (230 ft^2/1,000 acfm) when collecting fly ash with an electrical resistivity of 10^{12} ohm-cm. Sufficient base line data were obtained in the TCEP to show that it charged and collected the high resistivity fly ash as expected.

Figure 1-3 is a schematic of the TCEP design used in evaluation. As can be seen, it is a very simple system consisting of a manifold of welded 6-cm (2.375-in.) pipe. Water enters the bottom header, rises through the vertical pipes, and exits the ESP through the upper header. Corona is produced on wires which are suspended between adjacent pipes by a hanger system. Rapping is performed by means of a single-impact pneumatic rapper connected to the bottom header.

Table 1-1. Summary of Collection Enhancement, ESP

	SCA		E	W	Eff.
	s/m	(ft^2/1000 acfm)	kV/cm	cm/s	%
Unenergized ESP	12.7	64	--	--	50.0
Conventional wire-plate ESP	12.7	64	2.76	45	90.7
TCEP alone	1	5	5.16	157	71.0
Wire-plate ESP following TCEP	12.7	64	2.76	84	96.1
Combination of TCEP and ESP	13.7	69	--	--	98.9
Conventional ESP required for above efficiency	45.5	230	--	--	98.9

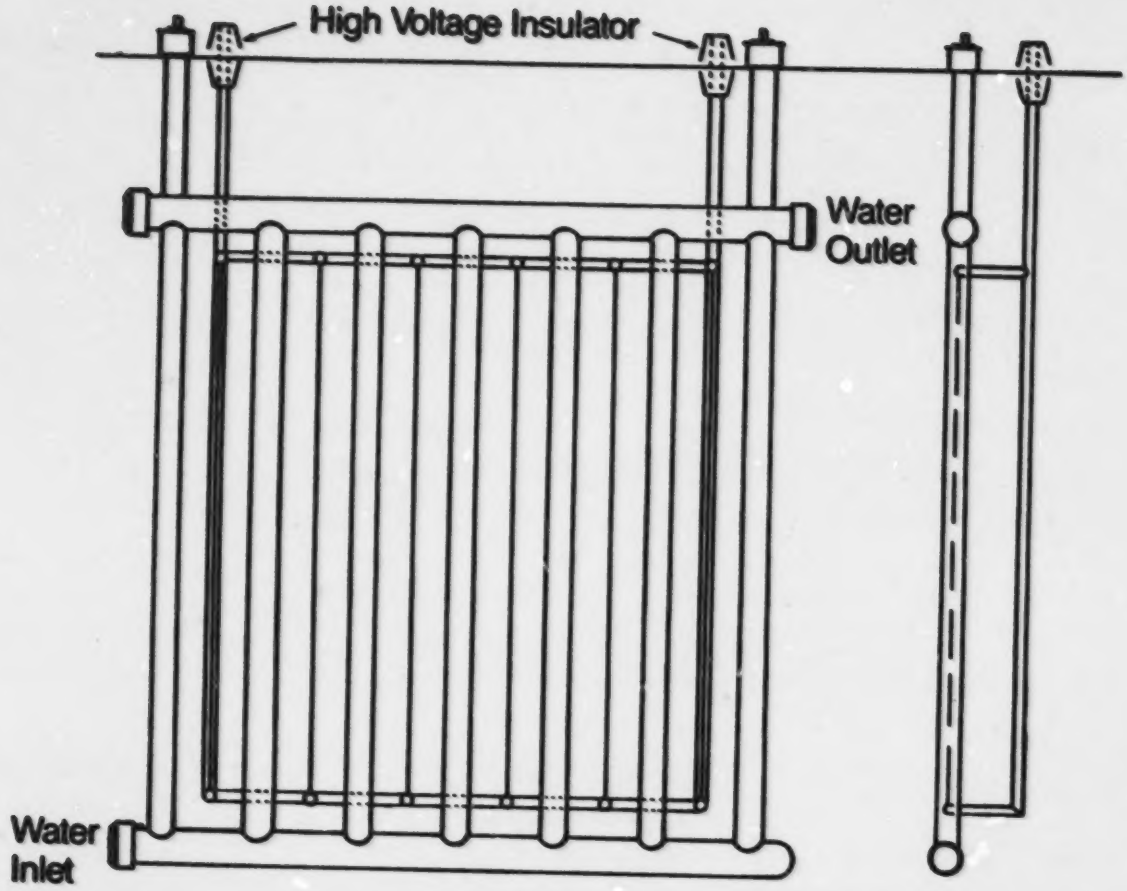


Figure 1-3. Schematic of temperature-controlled electrode precharger used in pilot scale evaluation.

Cooling water is circulated through the prechargers in a closed loop system. The circulation system consists of the following components: a pump with a bypass to control flow, a water-to-water heat exchanger cooled by plant water, and an automatic valve on a bypass of the heat exchanger to control the inlet temperature to the prechargers. Each precharger has a flow meter, thermocouples, and valves to monitor and control the flow through the manifold. The closed loop system is used because it provides an easy means of controlling the water quality in the pipes. Since corrosion or fouling on the inside of the pipes would hamper heat transfer, water treatment could be provided in a closed loop. This is probably the design that would be used in a full-scale ESP. It is estimated that the cooling water required from the plant for a full-scale ESP with four prechargers added would be below 1 percent of the total plant cooling water flowrate and, therefore, would not appreciably impact the cooling tower heat rejection capacity.

Further pilot-scale testing of the water cooled precharger was conducted at EPA[5] utilizing conventional wire-plate collectors in a multistage ESP. The ESP had cooled pipe chargers and conventional collectors in alternating sections. The test conditions and ESP configuration are summarized in Table 1-2.

The ESP operating conditions and penetration measurement are shown in Table 1-3. As can be seen from this table, with very low current (-10 μA) in the wire-plate sections of the ESP, the collection efficiency was approximately 96 percent. For the direct current tests with an average current of 610 μA, the average efficiency increased to 97 percent. When the two collector sections were pulsed (750 μA average current), the average collection efficiency increased to 98 percent. When the prechargers were both turned off and the ESP operated under pulse conditions, the collection efficiency dropped to 91 percent. The results with 0.95-cm (3/8-in.) corona electrodes show that even higher efficiencies are possible because of the resulting higher field produced by these electrodes.

The TCEP has been referred to elsewhere as the Cooled Pipe Precharger or the Cooled Pipe Charger/Collector. These names were used to emphasize the main geometric features of the device and also that not only does the device charge particles but, due to the high electric fields and high current densities, it is also a good collector. The new term TCEP was chosen because the temperature of the collector electrodes may be above, the same as, or below that of the gas stream, depending on the application.

Figure 1-4 shows the means for retrofitting the TCEP in a conventional ESP. The pipe manifold is mounted in the space between electrical sections. Nearly all ESP's have sufficient space between sections for installing the manifold. The pipes are suspended from the top of the ESP, and appropriate high voltage feedthroughs are provided for suspending the corona electrode. The TCEP is installed through an opening which is cut into the side wall of the ESP so that the pipe manifold can be inserted between collector sections. When cooling is required, coolant is pumped through the pipes. A simple throttle valve maintains proper flow, and the coolant can be passed through the plant's evaporative cooling tower. The added heat load on the cooler is a fraction of 1 percent. No modifications need to be made on the rest of the

Table 1-2. TCEP Tests With Conventional ESP at EPA Laboratory

Test conditions	
Temperature	148.9 °C (300 °F)
Gas flow	0.47 m^3/s (1,000 acfm)
Moisture	4 percent
Ash resistivity	9×10^{11} ohm-cm
ESP configuration	
Channels of flow	One
Plate spacing	25.4 cm (10 in.)
Wire spacing	22.9 cm (9 in.)
Wire size	0.32 cm (1/8 in.)
	0.95 cm (3/8 in.)
Gas velocity	1.5 m/s (5 ft/s)
Number of TCEP's	Two
ESP SCA	12.7 s/m (64 ft^2/1,000 acfm)

Table 1-3. Results of TCEP and Conventional ESP Tests at EPA Laboratory

	Direct Current		Pulsed
Tests With 0.32-cm (1/8-in.) Discharge Electrodes in the Collector Section			
No. Tests	5	9	9
Ave. collector voltage, kV	32	35	32
Ave. collector current, μA	~10	610	750
Penetration	0.042	0.031	0.017
Efficiency, %	95.8	96.9	98.3
Penetration with TCEP off	--	--	0.093
Efficiency with TCEP off, %	--	--	90.7
Tests With 0.95 cm (3/8-in.) Discharge Electrodes in the Collector Sections			
No. Tests	4	4	--
Ave. collector voltage, kV	32	38	--
Ave. collector current, μA	~10	200	--
Penetration	0.016	0.008	--
Efficiency, %	98.4	99.2	--

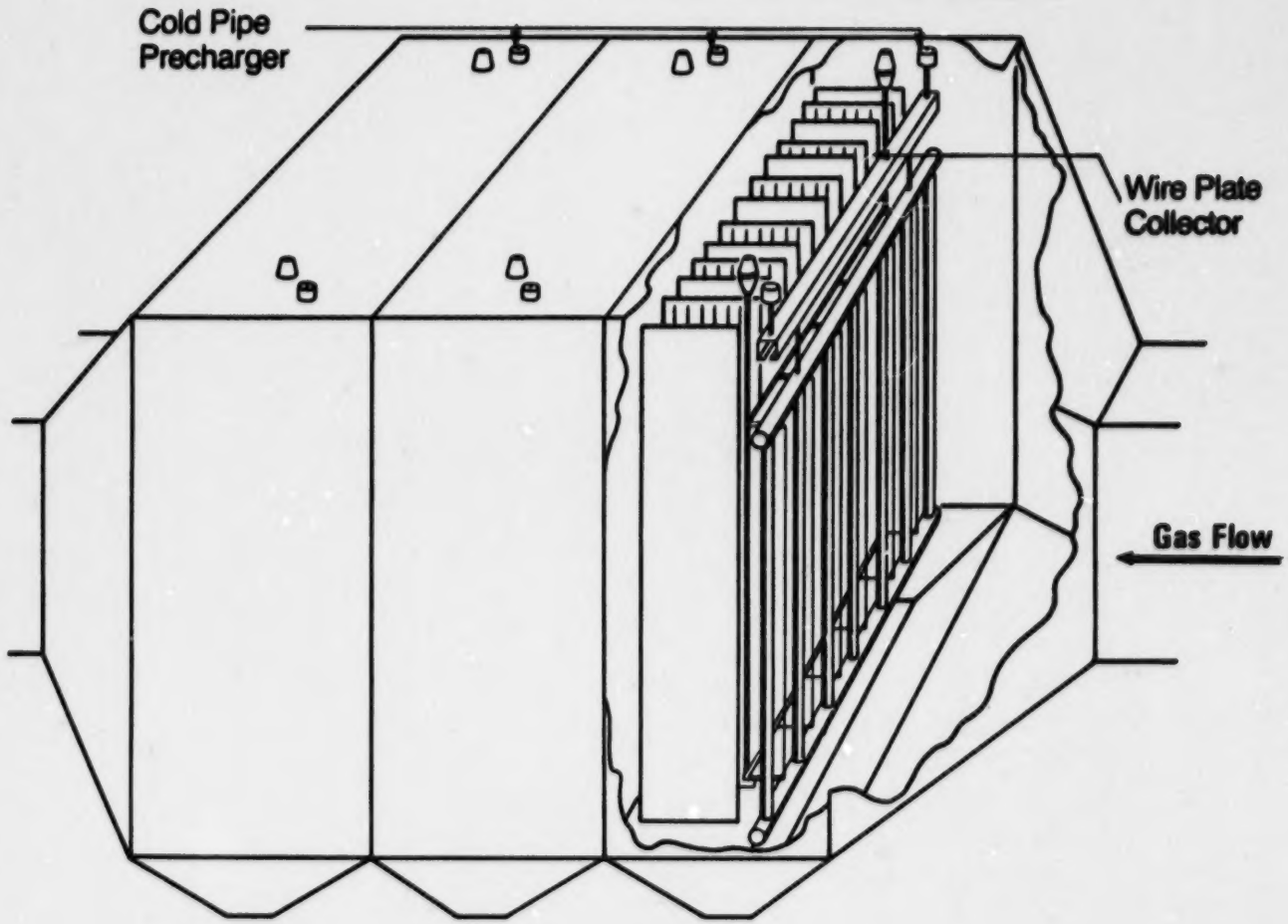


Figure 1-4. Prechargers retrofitted in an ESP.

ESP in many applications. However, additional enhancement of the effective SCA of the ESP may be obtained in many cases by using larger rod electrodes in the collector section. This is particularly true when collecting high resistivity fly ash.

SECTION 2

TEST FACILITY

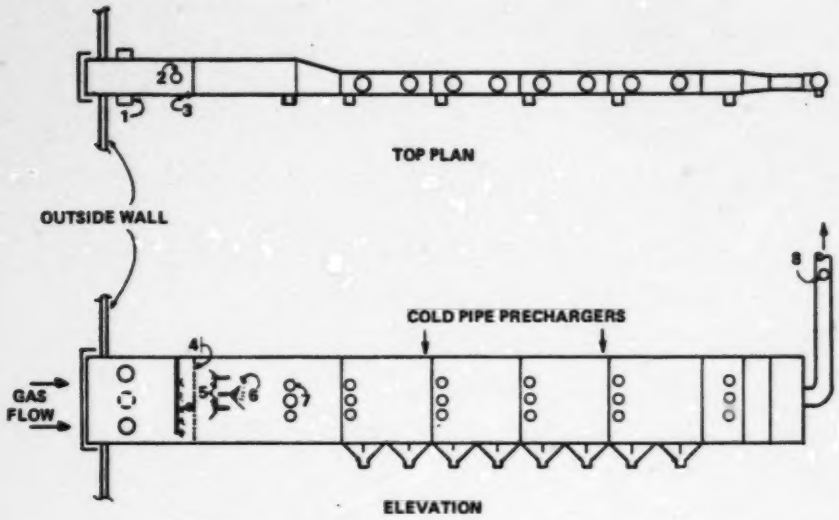
All the experiments were conducted in the ESP pilot-plant located at EPA's Air and Energy Engineering Research Laboratory (AEERL). The pilot-plant consists of a four-section, single-lane ESP operating at a flue gas capacity equivalent to 1,000 cfm. As shown in Figure 2-1, outside air is heated to 300 ^{o}F by a natural gas heater. Gaseous SO_2 is injected into the heated air to the desired concentration (usually 1,500 to 2,500 ppm) to simulate burning of moderately high sulfur coal. The ESP is operated under about 2 in. H_2O negative pressure so that no SO_2 is released to the room. Fly ash is aspirated counter currently into the simulated flue gas stream just before the cocurrent injection of the lime slurry. Lime slurry containing 10 to 20 percent solids is pumped through a spray nozzle designed to provide a spray pattern between rectangular and oval in the 50-in.-high x 15-in.-wide contact chamber. The atomized slurry droplets have a 1.5 to 2 s residence time in the chamber to evaporate most of the water. The evaporation causes a flue gas temperature drop and results in a relatively dry, powder-like product which contains the unused lime, the absorbed and reacted SO_2, and fly ash. The spray chamber consists of the entrance section and the first of four ESP sections with all the electrical internals (i.e., discharge electrodes) removed. The electrical configuration of the ESP is flexible but, for most experiments reported, two cold pipe prechargers were employed: one in the connecting space between sections 1 and 2 and one between sections 3 and 4. Conventional wire-plate electrodes were assembled in sections 2 and 4. As shown in Figure 2-2 after the ESP, the flue gas goes through a venturi scrubber and a draft fan before it is released to the atmosphere. The venturi scrubber is used to "polish" the flue gas so that no residual SO_2 or particulates are emitted from the test facility. Detailed descriptions of the major components of the test facility are presented below.

NOZZLE

The spray nozzle is the critical component of the test facility. Its function is to atomize the lime slurry into fine droplets and spray the droplets into the ESP in an acceptable pattern. The acceptable spray pattern should cover the whole ESP cross-sectional area to maximize the gas/liquid contact and SO_2 removal. On the other hand, care should be taken to minimize wall deposition resulting from impingement of slurry droplets on the wall.

As shown in Figure 2-3 the nozzle used for E-SO_x pilot-plant testing is a two-fluid nozzle "CasterJet" brand provided by Spraying Systems Company. This nozzle uses the impingement principle to generate the fine droplets. As shown in Figure 2-4, slurry is forced into the expansion chamber as a high velocity stream. This stream is shattered against a stainless steel target bolt to produce fine droplets. An air stream rushes past the target bolt, and further droplet breakup results. A spray pattern between a rectangle and an oval is provided by the CasterJet nozzle orifice.

Flowrate, air consumption, and spray droplet size of the spraying water are shown in Figures 2-5 and 2-6. It was found that air and water flowrates obtained by extrapolating the curves in Figure 2-5 agreed with pilot-plant



1. NATURAL GAS BURNERS
2. SO_2 INJECTORS
3. BURNER TEMP. CONT. T.C.s
4. PERFORATED PLATE
5. ASH INJECTORS (AGAINST GAS FLOW)
6. ATOMIZER TIP
7. SAMPLING PORTS
8. OUTLET SAMPLE TAP

Figure 2-1. EPA E-SO_x pilot facility, 1000 acfm (28 m^3/min) ESP with spray zone.

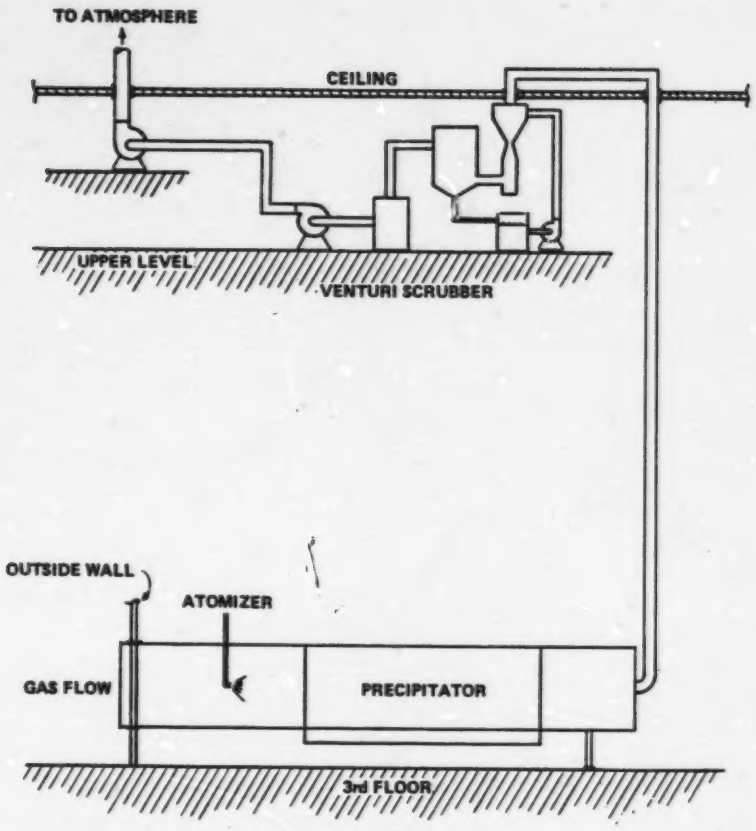


Figure 2-2. EPA E-SO_x pilot facility schematic.

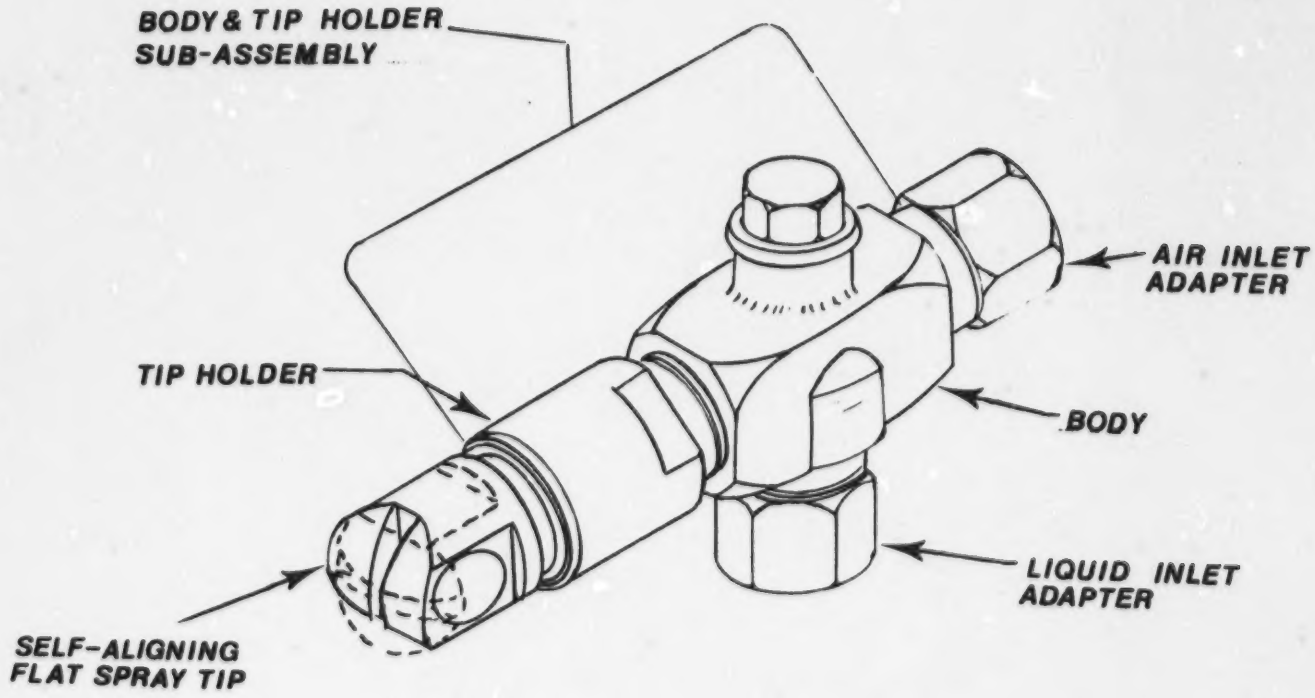


Figure 2-3. CasterJet spray nozzle.

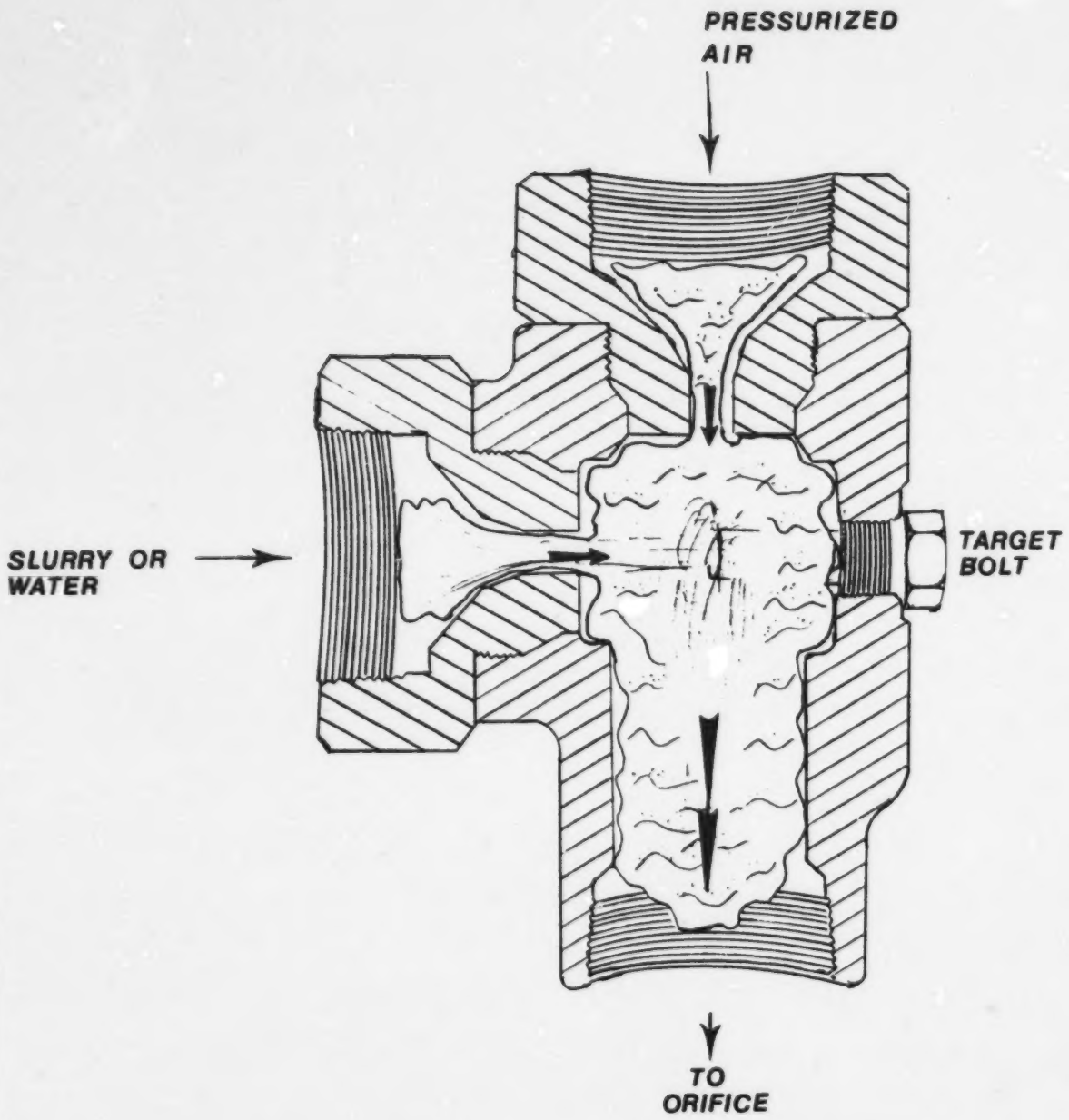


Figure 2-4. Atomization of CasterJet nozzle.

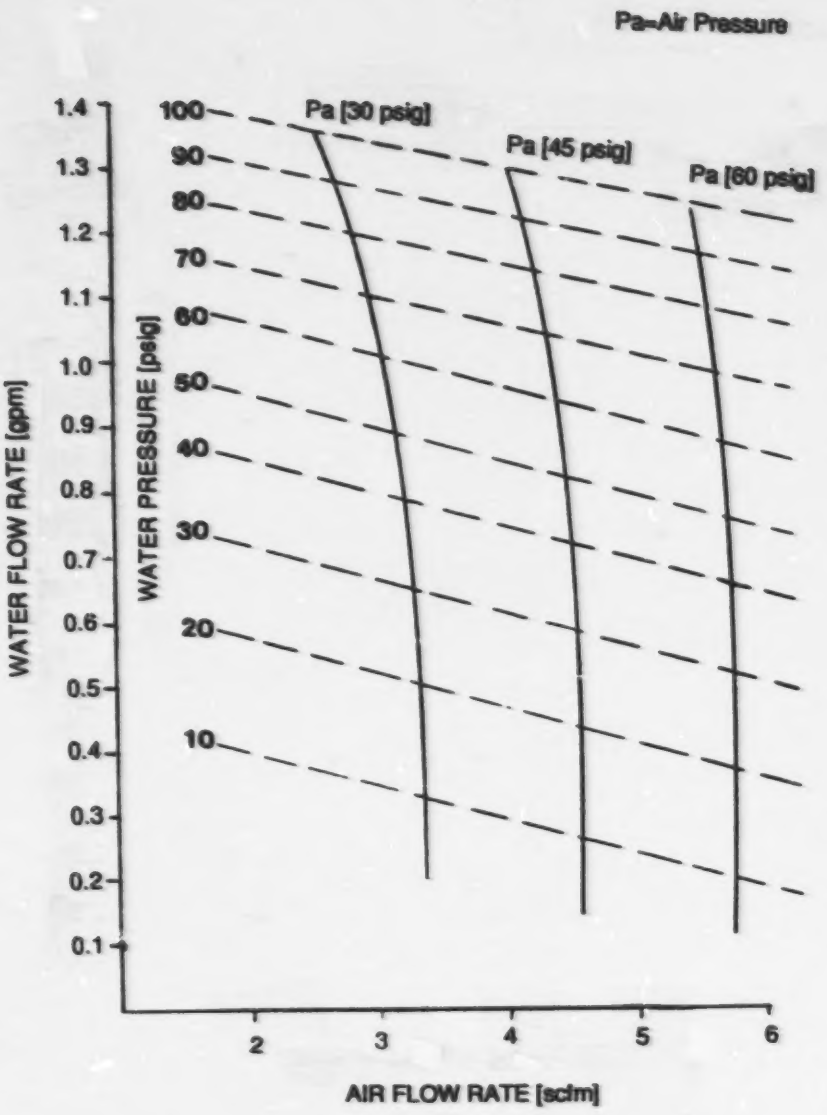


Figure 2-5. Performance curves of CasterJet nozzle.

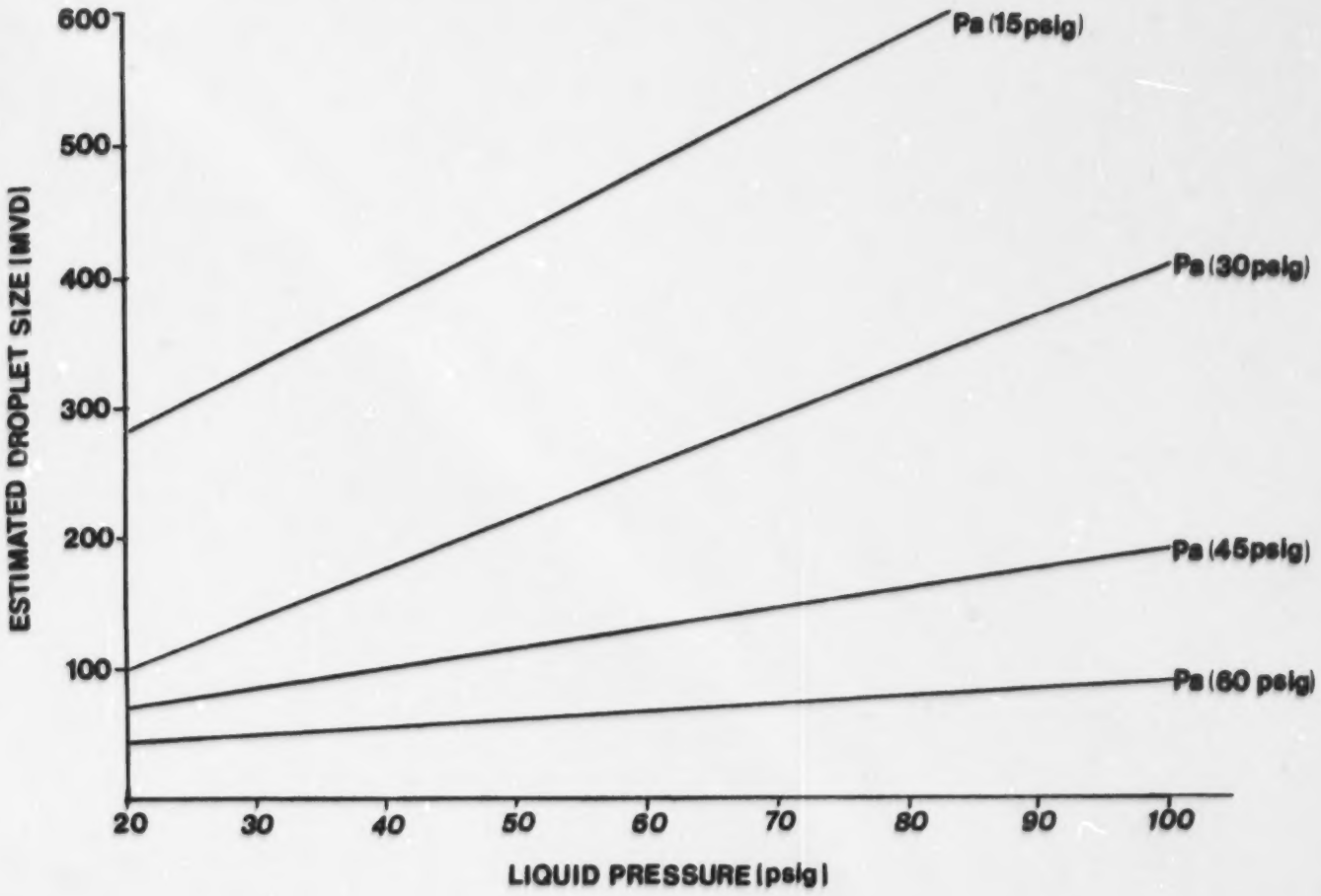


Figure 2-6. Droplet size distribution curves of CasterJet nozzle.

data at air pressures up to 100 psig and water pressures up to 30 psig. As mentioned, a stainless steel target bolt was used for these tests. The performance and durability of the target bolt were generally satisfactory if no fly ash was present in the lime slurry. For commercial and long-term application, a target bolt made of a special alloy such as silicon carbide or a ceramic material will be necessary for corrosion and erosion resistance.

SO_2 SUPPLY SYSTEM

The SO_2 supply system is shown in Figure 2-7. This system supplies SO_2 in gaseous form from four 150-lb cylinders through a heated sample line and into the ESP. The cylinders are located in a shed outside the laboratory. The shed is equipped with an automated ventilation system and space heaters to maintain constant temperature (approximately 85 ^{o}F) and an SO_2 detector which alarms at 20 ppm SO_2. The cylinder connection system consists of 1/4-in. stainless steel lines and fittings. A cutoff valve is provided to avoid any back flow into the SO_2 cylinder during nitrogen purge. The joints are arranged so that four cylinders are connected in parallel. The energy supply for SO_2 evaporation is provided by a thin film of water flowing over the cylinders and into a recirculation tank (Figure 2-8). The heat lost to evaporation is replenished by a water heater. The heater is thermostatically controlled, and the cutoff temperature is set at 85 ^{o}F. A backup thermostat which will shut off the heater and bath should the water temperature exceed 85 ^{o}F is installed in the bath water supply line. Therefore, the maximum water temperature will never exceed 85 ^{o}F. The vaporized SO_2 then flows through an insulated and heat-traced SO_2 supply line and into the ducting upstream of the ESP. The SO_2 supply line is a single continuous line with 1/2-in. Teflon™ core designed to withstand up to 400 ^{o}F and 500 psi. The temperature of the heat-traced line is maintained above 80 ^{o}F but below 185 ^{o}F to avoid SO_2 condensation and plugging problems. The SO_2 supply line has 1/2-in. thermal insulation, a reinforced stainless steel wire braid, and a scuff-resistant jacket. The electrical insulation is fiberglass-reinforced silicone rubber. The heating element of nickel alloy is completely sealed within the structure of the line. The pressure of gaseous SO_2 inside the supply line is controlled by a regulator and never exceeds the SO_2 vapor pressure (about 50 psi), which is controlled by the temperature of the water film. The pressure drop across the supply line is estimated to be less than 2.5 psi, which is overcome by SO_2 vapor pressure; thus, an extra pump is not required.

ELECTROSTATIC PRECIPITATION

The pilot electrostatic precipitation used for the tests being reported (as shown in Figure 2-9) was designed with the following features:

1. The ESP can be operated over a temperature range of ambient to 650 ^{o}F and at gas velocities from 0.3 to 6 m/s (1 to 20 fps).

2. Gas velocity distribution through the ESP is uniform: normalized standard deviation is less than 0.25.

3. Sampling ports at the inlet and outlet and between the electrical sections permit measurements of gas velocity distribution, mass

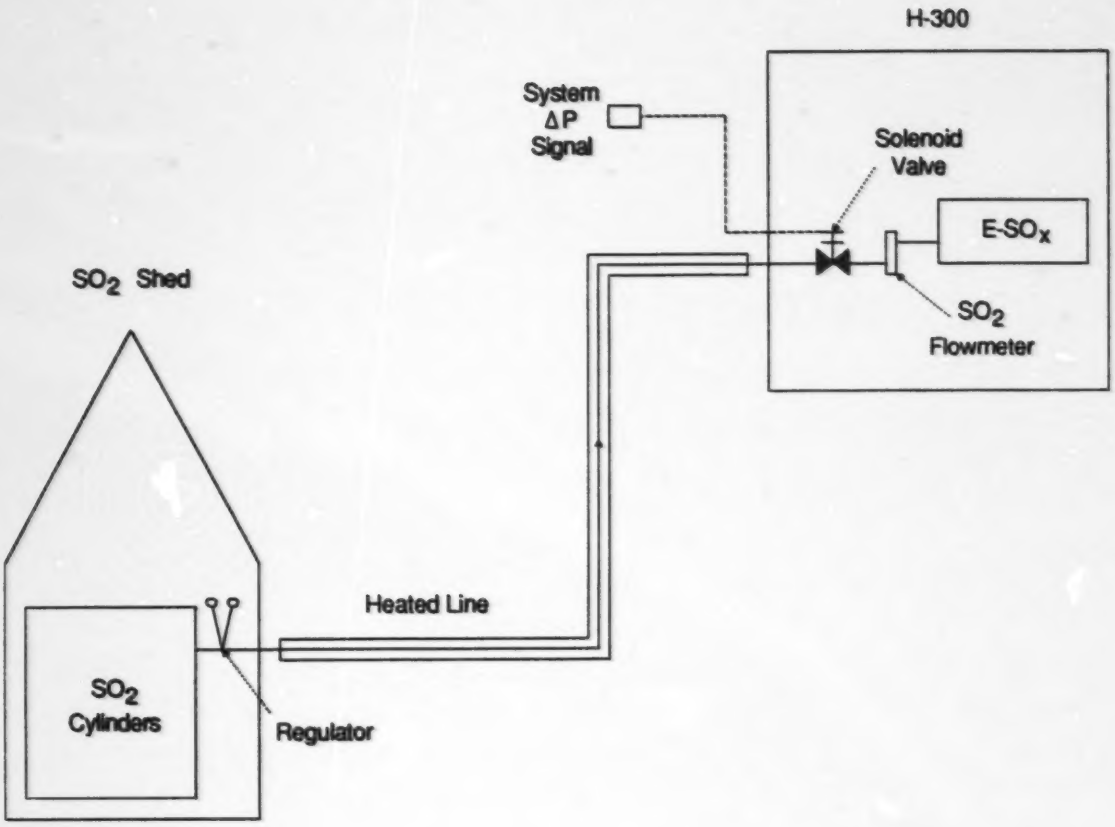


Figure 2-7. SO_2 supply system.

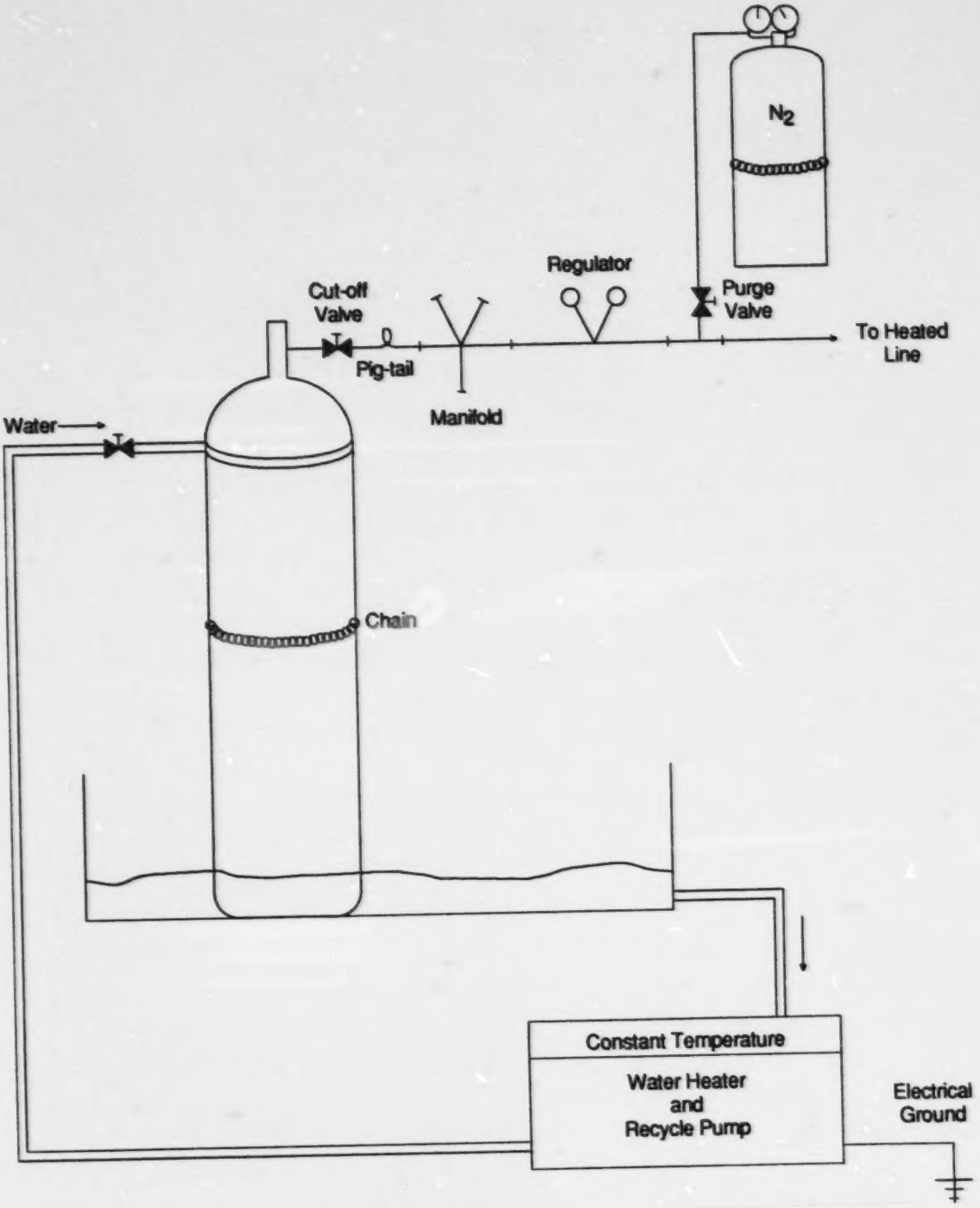


Figure 2-8. SO_2 supply system vaporization detail.

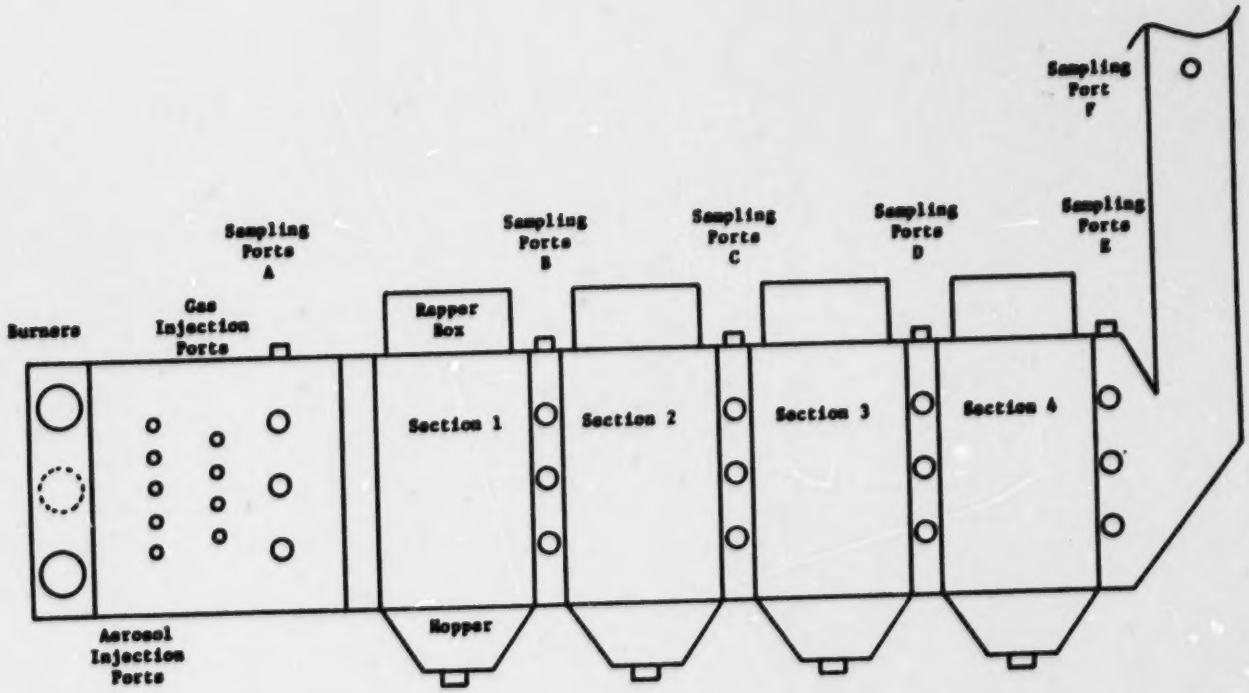


Figure 2-9. Diagram of pilot-scale ESP.

loading, temperature distribution, particulate resistivity, and gas composition.

4. Total gas volume flow is measured at the ESP outlet.

5. Extensive baffling maintains sneakage through the ESP as low as practical.

6. Gases can be injected upstream of the precipitator.

7. The collection plates are 1.2 m high, and plate-to-plate spacing can be varied from 12.7 to 38 cm (5 to 15 in.); wire-duct geometry is used.

8. The SCA of the ESP is 25 $m^2/m^3/s$ (128 ft^2/cfm) at a plate spacing of 23 cm and a gas velocity of 1.5 m/s.

9. There are four electrical sections in the direction of flow, and there is only one lane for gas flow.

10. The collector electrodes are isolated from ground so that the current to them can be measured directly.

11. The number of corona wires, wire-to-wire spacing, and type of wire electrode used can be changed easily.

12. The power supplies can operate to 200 kV with current up to 10 mA, half- or full-wave rectified, filtered or unfiltered.

13. Current and voltage waveforms can be displayed on an oscilloscope for monitoring.

14. Currents and voltages for all sections, the temperatures of the inlet and outlet of each section, and the pressure drop across the flow measuring orifice are measured, displayed digitally, and can be recorded on a line printer.

Table 2-1 lists the important dimensions and sizes of the ESP internals used for the E-SO_x tests. All the wires and electrical parts in sections 1 and 3 were removed before the pilot-plant tests. Conventional wire-plate electrodes were assembled in sections 2 and 4. In effect, this reduced the SCA from 25 s/m (128 ft^2/cfm) to 12.5 s/m (64 ft^2/cfm) plus the precharger area. The two cold pipe prechargers (see Figure 2-10) were installed in the space between sections 1 and 2 and the space between sections 3 and 4. Water was used as the coolant to control the temperature of the precharger.

SO_2 AND PARTICULATE SAMPLING SYSTEMS

SO_2 was measured by continuous emission monitors. To take into account the air inleakage, sampling port F at the ESP exit (see Figure 2-9) was used for SO_2 measurement before and after the slurry spray. The SO_2 efficiency was calculated as:

Table 2-1. EPA ESP Specifications and Operating Conditions

Inlet gas temperature	300 ^{o}F
Plate spacing	9 in.
Plate size	16 sq ft (4 x 4) each
No. of plates	8
Wire spacing	9 in.
Wire diameter	1/8 in.
No. of wires per section	5
No. of cold pipe prechargers	2
Cold pipe diameter	2 1/4 in. OD
Cold pipe outlet coolant temperature	<90 ^{o}F
Cold pipe spacing	7 in.

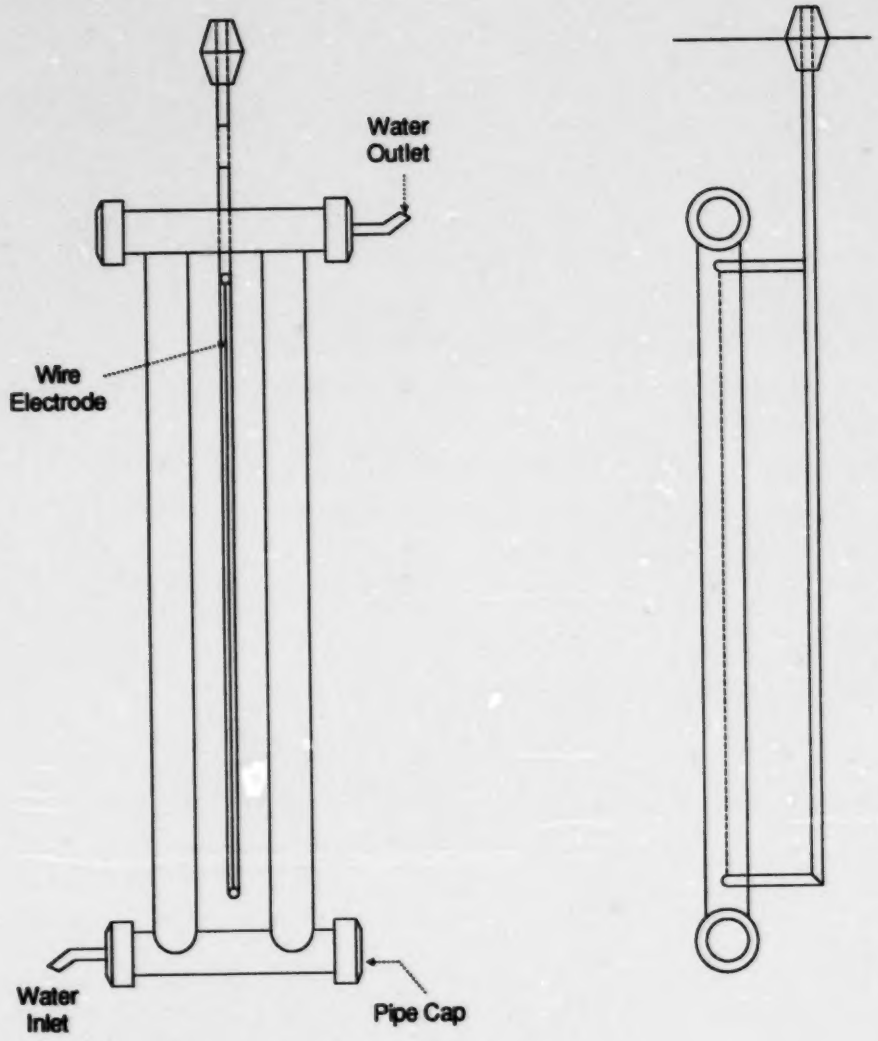


Figure 2-10. Schematic of temperature-controlled electrode precharger used in pilot-scale evaluation.

$$SO_2 \text{ removal} = \frac{[SO_2] \text{ before slurry spray} - [SO_2] \text{ after slurry spray}}{[SO_2] \text{ before slurry spray}} \times 100\%$$

The SO_2 sampling system included a condenser, an ice bath, and a filter (see Figure 2-11). Therefore the SO_2 concentration, $[SO_2]$, measured corresponds to the dry basis.

Fly ash particulate mass and size distributions were sampled by an in-situ inertial cascade impactor (MR-2 Series 1500). The cascade used (see Figure 2-12) is a second generation stack impactor designed to reduce errors in particle sizing. The particulate samples were collected and sized aerodynamically in the stack at isokinetic conditions. A Method 5 type sampling train was adapted as a cascade test train. The arrangement of the test train is shown in Figure 2-13. Typically, the sampling duration ranges from 10 to 30 min depending on the grain loading and flue gas flowrate. For E-SO_x pilot testing, sampling ports B and E shown in Figure 2-9 were used. A sampling probe was inserted into the center (through the middle port) of the ESP at each sampling location. The ESP particulate removal efficiency was calculated as:

$$\text{Particulate removal} = \frac{[\text{Particulate}]_B - [\text{Particulate}]_E}{[\text{Particulate}]_B} \times 100\%$$

The particulate concentration, [Particulate], was obtained by dividing the total weight of the particulates collected by the gas sample volume and expressed as grains per cubic foot.

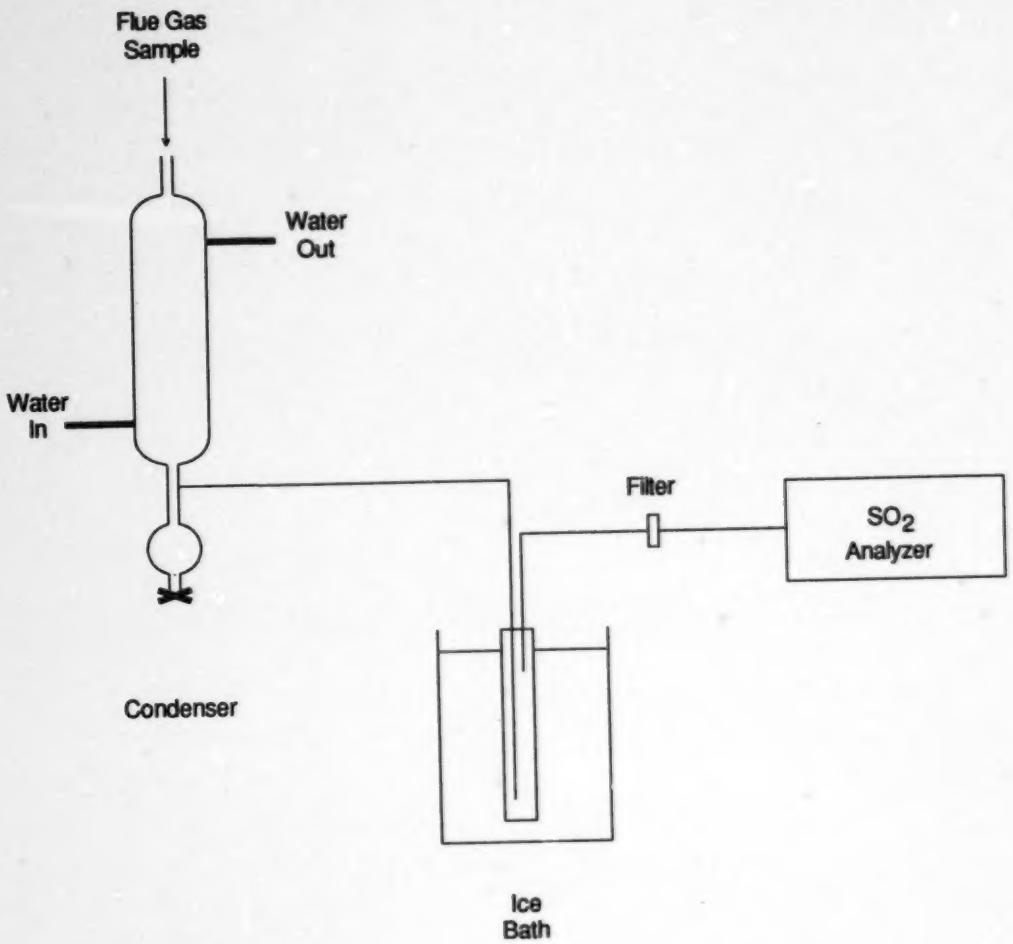


Figure 2-11. SO_2 sampling system.

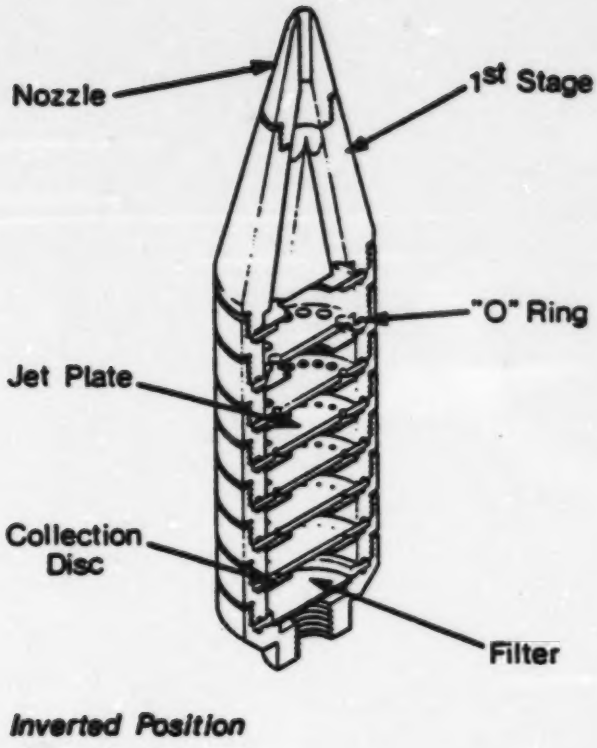


Figure 2-12. Assembly drawing of series 1500 inertial cascade impactor.

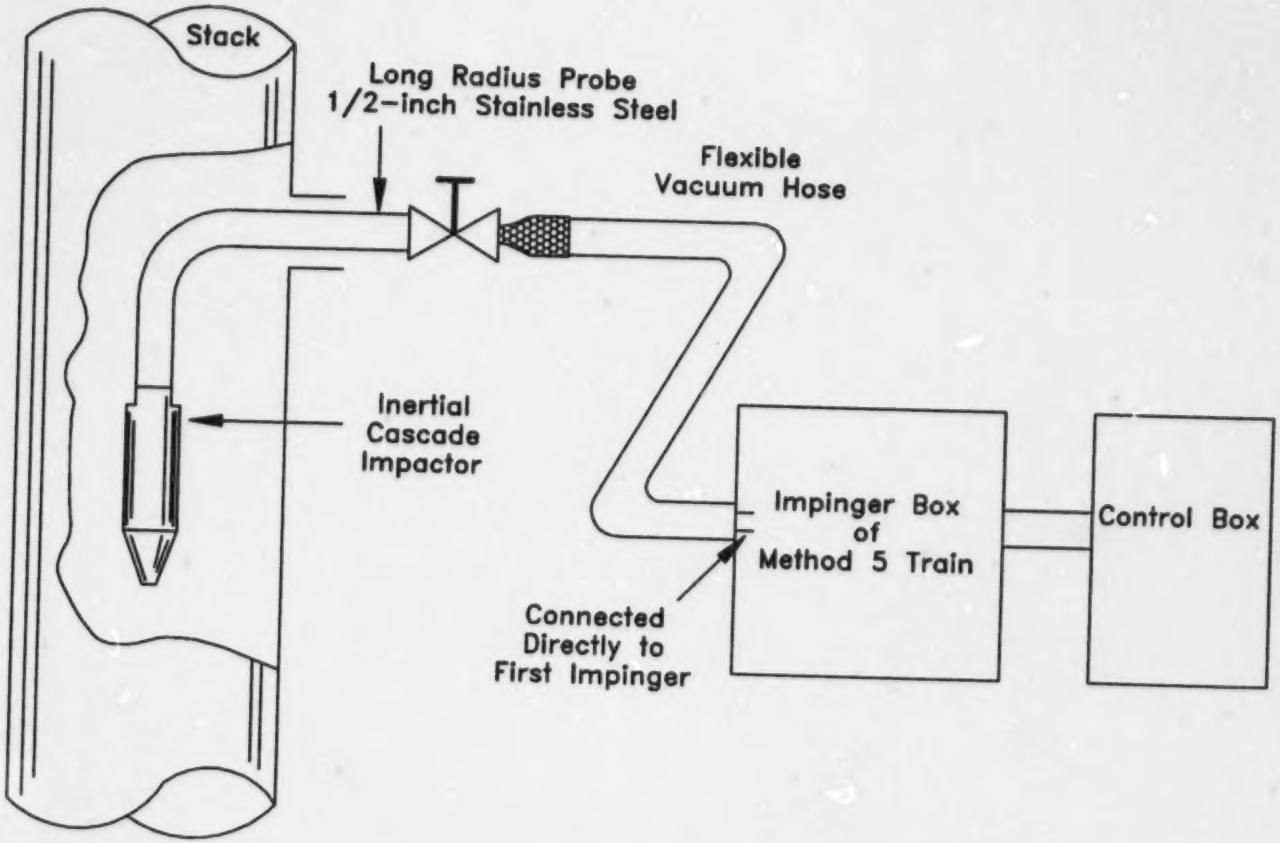


Figure 2-13. Impactor source test train.

SECTION 3

DISCUSSION OF OBJECTIVES AND TECHNICAL APPROACH

The E-SO_x pilot demonstration project had as an objective the testing of the concept at large scale in the field (Ohio Edison's Burger Station). Before the large-scale field testing began, small pilot-scale research was needed to define the limits of the E-SO_x process, and to develop the data base that was to be required. A test plan was developed to guide the small pilot-scale (1,000 acfm) research effort carried out at the EPA/AEERL test facility described in section 2 to study the process parameters and to provide a data base that was to be required for the larger pilot study.

OBJECTIVES

1. To advance E-SO_x from concept to a feasible process insofar as can be done on the facilities that are available. Development of a process includes both satisfactory SO_2 removal from a simulated flue gas stream and satisfactory performance of the remaining sections of the modified ESP.

2. To coordinate tests with the other partners in the overall E-SO_x effort [i.e., Babcock & Wilcox (B&W) and Southern Research Institute (SRI)], to resolve problems quickly or to verify results that may arise from the research on E-SO_x that is being conducted in the several laboratories.

3. To support the large pilot evaluation effort during design, installation, and testing by providing smaller scale test data that may be helpful during any one of the evaluation stages. Support is likely to be in the form of troubleshooting to get quick answers when the actual pilot testing began.

TECHNICAL APPROACH

To accomplish the objectives stated above, research was conducted that generally falls within three categories of experiments:

1. Establish baseline and general performance curves for the E-SO_x process through a study of the many variables that may affect the process. The baseline and performance data include results of SO_2 removal, fly ash interaction with time and effect on performance, and the effect of variables on ESP performance. It is within this classification of experiments that most of the basic parameter studies are to be conducted. These include process parameters, slurry and fly ash properties, and mechanical and electrical changes to the ESP.

2. Evaluate site-specific conditions that relate to the planned large pilot installation insofar as possible. Simulate the conditions relative to flue gas composition at the Burger Station including metering of Burger fly ash. Evaluate procedures, materials, and equipment relating to SO_2 removal or ESP performance that are

discovered or suggested by the research conducted at B&W or SRI which fit within the E-SO_x concept. Coordinate special experiments with B&W or SRI that may require involvement of all research facilities.

3. Evaluate technological advances that may enhance the original E-SO_x concept which include refinements in the sorbent system or in the particulate capture system. Additives and recycling fall within this category, which may be thought of as a second generation of E-SO_x. This approach is generally expected to occur within the latter phases of the project, and the likelihood of occurrence depends on the success of reducing the original concept to actual practice.

The techniques used to determine the effect of major parameters (see Table 3-1) or to evaluate an innovative procedure varied. The early experiments in which lime slurry was sprayed without SO_2 added to the air pulled through the ESP helped to establish limitations on slurry concentration, select a suitable nozzle, and determine a baseline for ESP performance. Generally, for parametric evaluations, a program matrix was followed. Results of each run will add to the data base. A standard operating procedure was followed so that, in evaluating one or more parameters, procedural variables were kept constant.

Table 3-1. Major E-SO_x Parameters

Normal parameters	Probable range
Air inlet temperature, ^oF	250-400
Outlet approach to saturation, ^oF	40-80
Inlet SO_2 concentration, ppm	700-2,500
Stoichiometry	1-3
Slurry solids, %	0-30
Fly ash loading, gr/ft^3	0.5-10
Nozzle air, psi	60-120
Slurry feed rate, gph	5-20

Other variables to be evaluated:

Type of lime with respect to particle size
Type of lime with respect to composition
Type of fly ash
Type of nozzle
ESP internal arrangement
ESP electrode size
ESP field voltage
Cold pipe precharger voltage

Dependent variables:

SO_2 removal
Sorbent utilization
Wall effects
Ash moisture
ESP VI behavior
ESP non-ideality
Nozzle operating window
Ash particle size
Ash resistivity

SECTION 4

DESCRIPTION OF EXPERIMENTS AND DISCUSSION OF RESULTS

The primary objectives of the E-SO_x experiments carried out at EPA using the 1000 acfm modified pilot ESP were to verify E-SO_x as a competitive retrofit process for SO_2 removal and to determine the critical parameters which influence the degree of SO_2 removal. Once the critical factors were determined, they could be adjusted within limitations of the process to give the best conditions for SO_2 removal and sorbent utilization. To meet these objectives, experiments were planned to investigate impacts of indirect variables as well as those directly influencing the lime slurry/SO_2 reaction.

The flue gas SO_2 concentration is monitored at the ESP exit just before the gas leaving the ESP enters the venturi scrubber. A removal test requires 6 to 7 hours with about 4 hours of actual sorbent spraying. The remaining time is required for start-up in which the air flow, fly ash injection rate, and SO_2 delivery are adjusted for uniform gas flow through the ESP. At the end of the run, water spray replaces the slurry spray until once again there appears to be a steady outlet SO_2 concentration. The SO_2 concentration exiting the system is lower than it was originally because of the wall effects; i.e., unreacted lime deposited on walls and fixtures reacting with the SO_2 in the gas. These effects vary, but they will decrease in relative significance as the size of the ESP increases in scale-up.

SELECTION OF SORBENT

E-SO_x utilizes a suspension of lime in water. Early experiments were conducted with a slurry of hydrated lime. However, the potential for attaining a smaller lime particle size though lime slaking resulted in a comparison between hydrated lime slurry and slaked lime at otherwise fixed conditions. Comparison of degree of removal is shown in Table 4-1. For a given approach to saturation at a constant stoichiometric ratio, the slaked lime performed better than the hydrate slurry. Similar results were obtained in experiments conducted by B&W. The improvement may be attributable to a difference in particle size or surface area. Brunauer, Emmett, and Teller (B.E.T.) surface area measurements showed the slaked lime to be about 30 percent higher in surface area. Since the use of slaked lime was preferred by virtue of cost as well as removal efficiency, most of the tests were conducted using slaked lime. Also in the economic study[1], the lowest cost scenario for E-SO_x made use of slaked pebble lime.

SO_2 REMOVAL DEPENDENCE ON CRITICAL FACTORS

A number of tests were performed in which only concentration and rate of injection of slaked lime were varied. In essence, this permitted an examination of the effect of the two most critical parameters on SO_2 removal: the temperature of approach to saturation ($\Delta T_A S$) and the stoichiometric ratio of calcium to sulfur (Ca/S) in the slurry/gas mixing. When other parameters are held constant, including spray chamber geometry, gas flow rate, SO_2 concentration in the gas, and the inlet gas temperature, these injection parameters can be manipulated to give a $\Delta T_A S$ and Ca/S combination. There is a lower limit on $\Delta T_A S$ for adequate droplet drying and an upper limit on the

Table 4-1. Comparison of SO_2 Removal by Slaked and Hydrated Lime at 2100 ppm SO_2

Lime	Approach to saturation* (^oF)	Calcium-to-sulfur ratio	SO_2 removal (%)
Hydrate	34	1.5	46
Slaked	36	1.5	54
Hydrate	38	1.1	32
Slaked	38	1.1	38
Hydrate	40	1.5	43
Slaked	40	1.2	43

* $^oC = {}^oF/1.8$

solids concentration for consistent spraying. The fixed conditions are listed in Table 4-2.

The removal of SO_2 as a function of approach temperature for various stoichiometric ratios is shown in Figure 4-1. This correlation between approach to saturation and SO_2 removal shows that good removal is possible at very low stoichiometric ratios, but only at very close approach temperatures. At these close approaches the droplets are not completely evaporated and excess moisture will pass into the ESP. The lower practical $\blacktriangle T_A S$ is believed to be in the 28 to 30 ^{o}F range. Stoichiometric ratios of 1.3 to 1.4 produced a removal of 50 percent or better at a 30 ^{o}F approach to saturation. Results indicate a marginal improvement in SO_2 capture at a ratio of 1.4 but the increase in ratio with a smaller return makes the higher ratios less cost effective. The leveling off of removal rate with increasing Ca/S is also reflected in the plot of percent removal as a function of Ca/S in Figure 4-2.

EFFECT OF FLY ASH

In most of the EPA tests, fly ash was added as a component of the flue gas. However, similar tests were run without fly ash to determine if fly ash interferes with the E-SO_x process. A comparison of the runs with and without fly ash at a given $\blacktriangle T_A S$ and Ca/S is given in Table 4-3. Obviously a slight variation in either $\blacktriangle T_A S$ or Ca/S has a greater effect than the fly ash. If there is a small SO_2 removal loss due to fly ash it can probably be compensated for by a small adjustment in one of the primary parameters.

EFFECT OF SO_2 CONCENTRATION IN EMISSIONS

The E-SO_x process installation at the Ohio Edison plant site will be evaluated on emissions from burning 3 to 3.4 percent sulfur coal. EPA testing has concentrated on simulated flue gas streams containing about 2000 ppm SO_2 which corresponds to the sulfur content of this coal. A limited number of tests were performed using 1500 ppm SO_2, and plans are to look at 2500 ppm SO_2. Data from the 1500 ppm tests are plotted in Figure 4-3. Comparison of Figure 4-3 with Figure 4-1 indicates that somewhat better removal is achieved at 1500 ppm for a given $\blacktriangle T_A S$. At a 30 ^{o}F $\blacktriangle T_A S$ and a Ca/S of 1.4, the removal runs about a 10 percent increment higher at the 1500 ppm SO_2 level. The 50 percent removal goal was achieved in both cases.

PARTICULATE REMOVAL

The second fundamental question about E-SO_x as a retrofit concerns maintenance of an acceptable level of particulate removal. The question arises because of the reduction in SCA with a simultaneous increase in particulate loading. In conjunction with the SO_2 removal testing, the ESP electrical configuration was varied to determine effects of the increased load and change in characteristics of the particulate matter collected by the ESP. With sections 2, 3, and 4 energized and containing 0.32 cm (1/8 in.) wires, the ESP has an 18.8 s/m (96 SCA). With only two of the sections energized, the ESP was reduced to 12.5 s/m (64 SCA). Cold pipe prechargers, located between sections 1 and 2 and between 3 and 4, could be activated, but the SCA would remain the same. The data tabulated in Table 4-4 show that high mass efficiencies were obtained during a 4-fold increase in particulate loading and

Table 4-2. E-SO_x Fixed Conditions for SO_2 Removal Studies

Air flow	28 m^3/min (1000 acfm)
Inlet temperature	149 °C (300 °F)
SO_2 concentration	2000 ppm
Fly ash concentration	1.9 g/l (1 gr/ft^3)
Nozzle configuration	Single two-fluid CasterJet oval spray pattern
Inlet chamber	1.5 m (5 ft) spray chamber plus 1.2 m (4 ft) ESP section

Table 4-3. Effect of Fly Ash on SO_2 Removal at 2000 ppm SO_2

ΔT_{AS}* (°F)	Ca/S	Fly ash+ (gr/ft^3)	SO_2 removal (%)
28	1.4	0	49
28	1.3	1.0	50
35	1.5	1.0	50
35	1.5	0.25	52
36	1.5	0	52
37	1.3	0	45
37	1.4	1.0	47

* °C ≡ °F/1.8
\+ g/m^3 = gr/ft^3 x 2.3

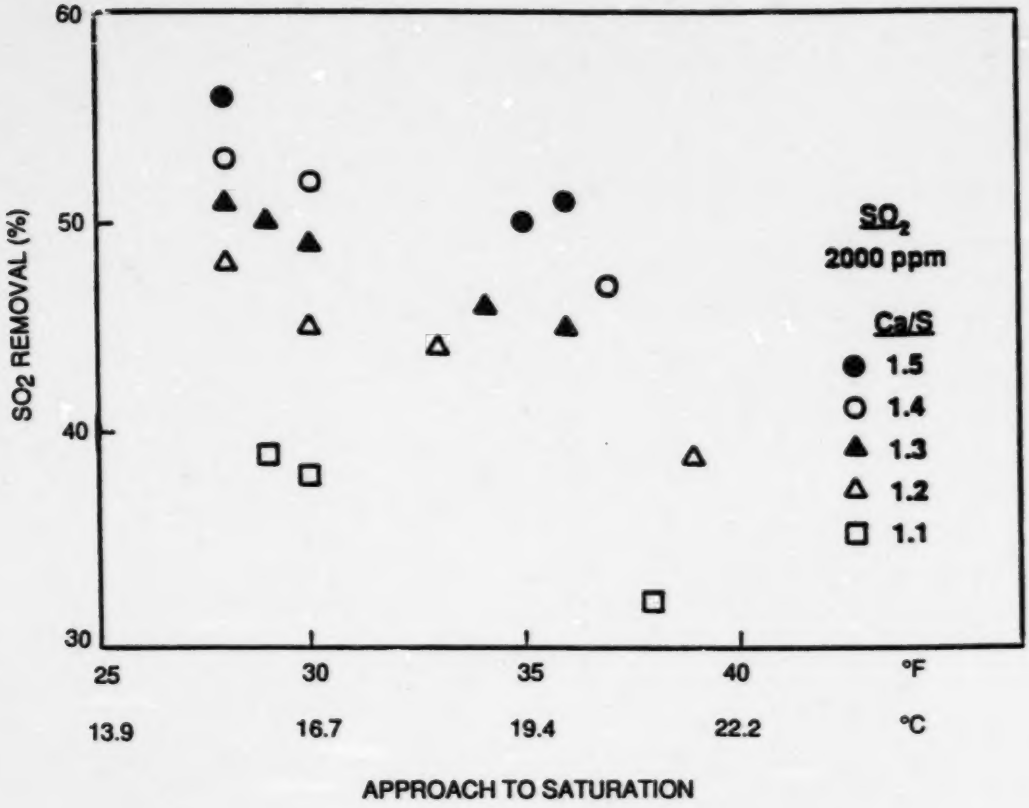


Figure 4-1. Effect of approach temperature on SO_2 removal at several stoichiometric ratios.

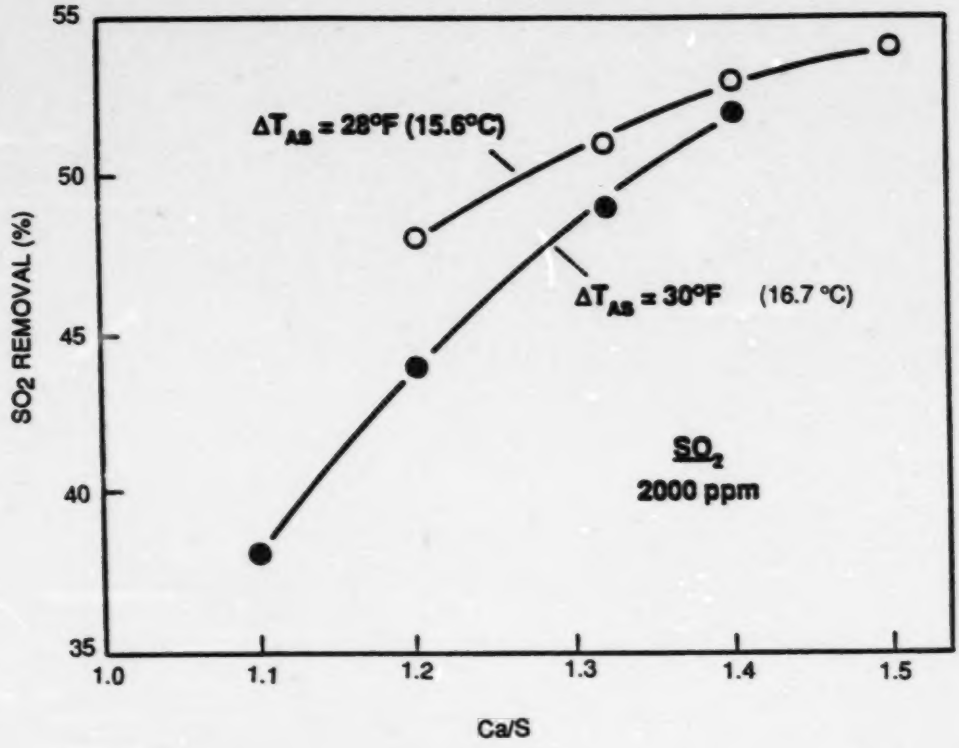


Figure 4-2. Effect of stoichiometric ratio on SO_2 removal at two approaches to saturation.

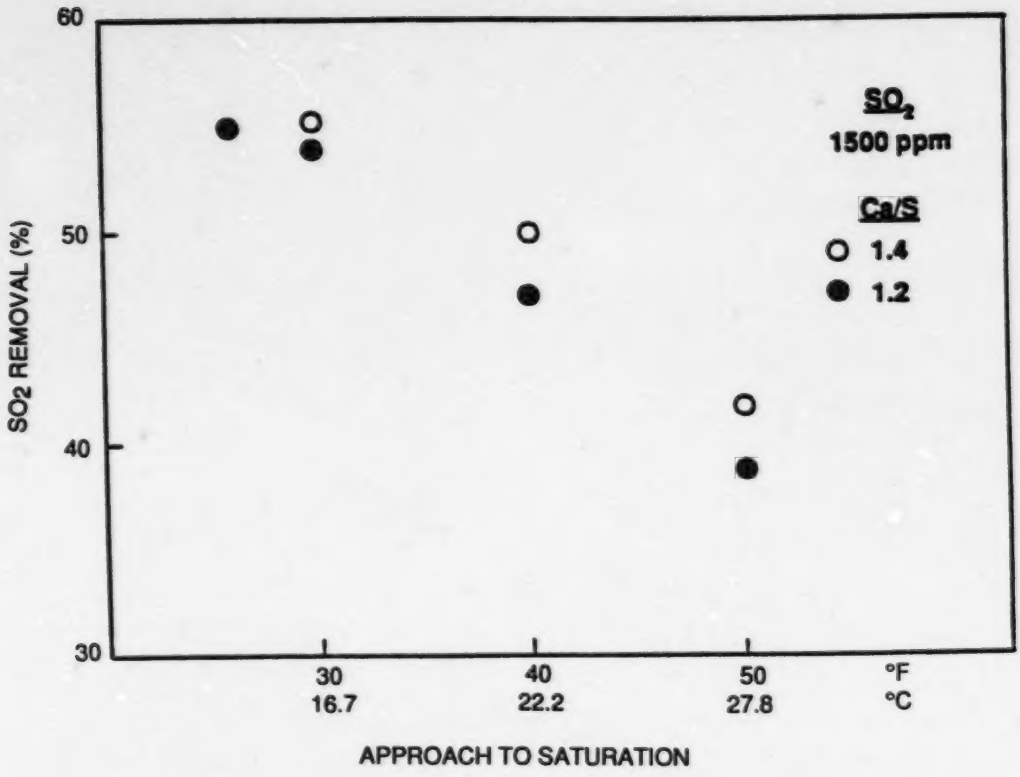


Figure 4-3. Effect of approach temperature on SO_2 removal at two stoichiometric ratios.

Table 4-4. E-SO_x Particulate Removal Efficiencies for Various ESP Electrical Configurations

Sections energized 38 kV	Cold pipe 38 kV	Approach temperature* (^oF)	Particulate	ESP efficiency (%)	Emission rate+ lb/10^6 Btu
2, 3, 4	Yes	30	E-SO_x & fly ash	99.5	0.017
2, 3, 4	No	30	Fly ash	97.9	0.032
2, 3, 4	No	30	E-SO_x & fly ash	98.5	0.030
2, 3	No	30	E-SO_x & fly ash	98.6	0.088
2, 3	No	35	Fly ash	95.6	0.058
2, 3, 4	No	100	Fly ash	97.6	0.030
2, 3, 4	Yes	100	Fly ash	97.8	0.038
2, 3, 4	Yes	160#	Fly ash	89.0	0.128

* $^oC = {}^oF/1.8$
\+ ng/J = lb/10^6 Btu x 430.5
\# No moisture injection

a 50 percent reduction in the SCA. There appears to be no significant change in efficiency with the amount of particulate as long as some moisture is present. The ESP emission rates listed in Table 4-4 also indicate that under E-SO_x conditions the ESP can meet or exceed the NSPS standard of 0.1 $lb/10^6$ Btu (43 ng/J). For fly ash only, the efficiency was reduced severely without moisture addition. In this case, the 38 kV could be maintained on the cold pipe precharger, but not on the wires because of back corona. Evaporation of water during the drying step lowers the temperature which accounts for the low resistivity of the lime sorbent/fly ash mixture in the E-SO_x process[8]. As a consequence of the low resistivity, back corona is not a problem.

It is evident from the data that the cold pipe precharger is not needed for its primary function which is to lower the resistivity of the ash. However, the cold pipe precharger may still be needed in some retrofit systems to serve as an efficient collector for the small space that it occupies in the ESP.

Table 4-5 is included to complete the particulate removal, electrical configuration description. In the table the voltage-current (V-I) information for a typical configuration is given along with rapper frequency for each field. The slightly lower voltage in the last field is a consequence of the dryer solids collected in that section.

SOLIDS DEPOSITION

For design purposes, it must be recognized that a majority of the particulate collection takes place in the spray chamber/first section portion of the ESP. An adequate hopper and conveyance system has to be provided in commercial units to take care of the increase in solids in the spray section. If a slurry spray configuration is built into the first section of an ESP as envisioned in the E-SO_x concept for commercial use, the existing hoppers and conveying system would have to be checked out for the increased solids fall-out. The data given in Table 4-6 are included to compare the solids collected in the several sections of the ESP. In this run, which is considered as a typical E-SO_x run that meets the criteria set for E-SO_x with respect to SO_2 removal and solid emission containment, approximately 47 percent of the solids were removed in the spray section and first section. In these portions of the ESP, the fallout is caused primarily by gravity and particle-wall collisions. Almost 40 percent of the particulate is removed in section No. 2 which contains the first electrical field of the modified ESP. The moisture content falls off with successive sections also, the highest moisture being in the spray chamber.

Table 4-5. ESP Conditions, Run No. 09128

Cold-Pipe Precharger at End of Section 1
1/8-in. Wires in Fields 2, 3, 4

Electrical Field	V (kV)	I (A)	Rapping interval (min)
1	38.3	0.460	5
2	38.0	0.252	10
3	38.3	0.176	30
4	35.2	0.146	60

Mass Loading:

Inlet	3.484 gr/ft^3
Outlet	0.015 gr/ft^3
Efficiency	99.6%

Table 4-6. Solids Deposition and Moisture Data

Run No.: 09128
SO_2 Conc.: 2500 ppm
Stoichiometric Ratio: 1.3
Lime Slurry Rate: 155 lb/hr
Slurry Solids: 19%
Fly Ash Conc.: 1 gr/ft^3
Approach to Saturation: 30 ^oF

ESP location description	Solids removed dry weight	Solids removed % of total	Moisture content (%)
Inlet (spray chamber)	42.8	27.8	
inlet floor			20.7
inlet walls			21.2
Section 1 (no electrodes)	29.0	18.9	3.4
Section 2 (collects from cold pipe precharger and 1st electrical field)	61.3	39.9	2.7
Section 3 (2nd electrical field)	17.8	11.6	1.3
Section 4 (3rd electrical field)	2.9	1.8	1.2

SECTION 5

CONCLUSIONS AND FOLLOW-UP

Experiments in the EPA facility have verified the potential for E-SO_x as a competitive retrofit for SO_2 removal and has determined the critical design parameters for a large scale evaluation. An SO_2 removal of 50-60% from a simulated flue gas representing emissions from a medium to high sulfur coal was achieved along with adequate particulate collection. Slaked lime slurry concentrations and rates of injection were adjusted to show that a combination of an economical calcium to sulfur ratio of 1.3 to 1.4 and a temperature of approach to saturation of 30-35 ^{o}C was sufficient to achieve the removal objective.

The primary immediate E-SO_x follow-up is occurring at the Burger Plant of Ohio Edison where the EPA, Ohio Coal Development Office (OCDO), B&W Research Division, and SRI are carrying out an evaluation of the process. The evaluation is being carried out in a 5 MWe (15,000 acfm) pilot ESP which is connected by a slipstream off of the main ducts between the boilers and the plant ESP. The work plan at this site has been designed to verify the SO_2 removal results and the ESP efficiencies that have been obtained in the in-house process and reported here. Having been done on a larger unit, the work should provide experience in design that will be more meaningful for a full-scale demonstration later. This pilot evaluation is slated for completion in late 1989 with reporting of results to follow in the spring of 1990. A description of the E-SO_x pilot unit and development of an experimental spray chamber for this unit has been reported [9, 10].

Future plans for the EPA in-house E-SO_x pilot unit call for experiments with waste product recycle to enhance utilization of the lime. Limited experiments thus far have been encouraging. However, the fly ash in the recycle causes excessive wear of ordinary nozzle materials of construction. Ceramic materials or hardened metals are available, but they increase the cost of exploratory work. Increased utilization may be possible through the use of additives to the slurry or by modifying the slurry spray pattern. These investigations will be reported later.

SECTION 6

REFERENCES

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APPENDIX A

DATA SHEET

E-SO_x

SO_2 DATA SHEET

Date_____
Slurry Conc._____
Type Sorbent_____
Nozzle Air Press._____
Nozzle Slurry Press._____

Minutes	Time	SO_2 wt.,lb. / R'meter	SO_2 Conc. Outlet ppm	Temperature Inlet °F	Temperature Out °F	Temperature W.B. °F	Slurry Weight lb	Solids Moist. %	Notes
0									
30									
60									
90									
120									
150									
180									
210									
240									
270									
300									
330									
360									
390									
420									
450									
480									

Comments:

APPENDIX B

QUALITY ASSURANCE DATA

A Quality Assurance Project Plan (QAPP) was issued for the reported pilot plant testing of E-SO_x process before start-up. The QAPP was classified as Level IV. The quality assurance objectives of this project were to ensure that data collected during the pilot plant testing were accurate and useful. Data obtained from the Level IV project are intended for use as guidelines for the selection of sorbents and test conditions in large pilot plant or field testing.

The QAPP required that the SO_2 analyzer be carefully calibrated for each run. Accuracy was checked against calibration standards. Measured experimental data were entered into the QA notebook. The operator recorded all the calibration data and process data for each run. The calibration data were taken before each run. The process data were taken every 30 min during the testing.

DISCUSSION OF DATA QUALITY

The major measurements made in the pilot plant evaluation of the E-SO_x process were SO_2 concentration, slurry solids, and slurry weight. The summary of measured parameters and their accuracy is presented in Table B-1. In all cases, the accuracy of measurements met or exceeded the quality assurance objectives listed in Table B-1.

It should be noted that the pulsed fluorescent SO_2 analyzer is sensitive to oxygen and moisture concentrations in the sample gas. Special care was taken to ensure that the span gas contained the same level of oxygen as the flue gas samples. A condenser and an ice bath were installed to ensure the consistency of all gas sample moisture contents. In addition, an electronic digital scale was acquired. The lime slurry tank was mounted on the scale to obtain instant reading and to improve the accuracy of the weight data.

Table B-1. Data Quality Summary

Measured parameter	Calibration method	Calibration accuracy (%) Planned	Actual
SO_2 concentration	SO_2 span gas	10	9
Slurry solids	Weighing	5	4
Sorbent feed rate	Stopwatch and weighing	10	4